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TREATMENT OF BONE DEFECTS

GLAS SRPSKI
Banja Luka
2000

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PREFACE

Treatment of bone defects is my second book dealing with bone loss management in orthopedic surgery. This book developed as a natural extension to the management of primary war trauma, a subject to which I devoted my first book *Manual of external fixation in management of war wound*.

In our contacts, Prof. dr. Augusto Sarmiento, Miami University Florida has given me idea for this book . In one of the letters he wrote:" …try to process results and final data, only doing so you would fulfill your obligation to unite your observations and experience…" I express my most sincere gratitude for His guidance and literature He shared generously with me.

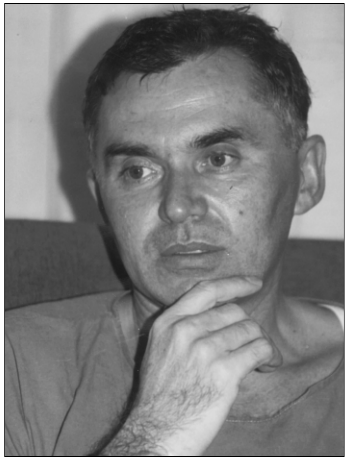
Beside importance which this book had when published, in the war time, experiences which I incorporated into are relevant for the injuries in peace-time as well. This makes me to believe that importance and applicability of this book reaches beyond time and space of its creation.

With regard to the bone defects or bone loss management, in this book I listed attitudes and achievements of foreign authors as well as conclusions which my colleagues and me made working at Hospital for the Orthopedic Surgery and Traumatology in Banjaluka.

I would like to thank to my parents, Dragica and Milan, for all they have given to me. I would also like to thank to my family, to my wife Gordana, to my son Milan and to my daughter Ivana who are both my sharpest critics and my best assistants.

Some problems are elaborated to the extent of their presence in day-to-day practice. It was my attempt to describe each area clearly, with practical and fact-based information. This book could serve as a textbook also, even dough it not my primary intention. The basic motive was to illustrate, in one place, in one book, all available methods for the reconstruction of bone defects.

The main intention of this book was to fill in the gap in our literature on orthopedic surgery as well as to offer a comprehensive knowledge to junior colleagues in the field of bone defect management in both war- and peacetime wound.



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I

HISTOLOGY AND PHYSIOLOGY OF BONE TISSUE

I - BONE TISSUE

Main functions of bone tissue are weight bearing and formation of osseous skeleton.

Bone tissue is the hardest tissue yet a tissue which is in philogenesis and ontogenesis the youngest one. This mineralized tissue, with close binding between organic and inorganic intercellulaar matrix, makes an unique biological entity. For unremitting metabolic functions, bone, continuously and permanently, degrades and re-structures. This makes a dynamic balance and the reservoir of calcium, phosphate and other ions in the body.

Bone tissue, a main element of skeleton, is composed of two components: cells and intercellular substance - matrix. Bone tissue is one of most dynamic tissue of our organism, thanks to rich vascularization, metabolism of minerals and continuous morphological and biochemical changes. There are three main types of cells in bones:

- osteoblasts,
- osteocytes and
- osteoclasts.

1. OSTEOBLASTS

Osteoblasts are mesenchimal cells, their shape and size depend on their functional activity. Active osteoblast are cubed cells, with round, eccentrically placed nucleus. Their cytoplasmic processes extend to contact other such cells. Cytoplasm is basophilic, full of grained endoplasmatic reticulum which produces osteoid ; with enlarged Goldgy organels and numerous mitochondrias. They origin from the pra-cells called pre-osteoblasts or osteoprogenitor cells.

In primary bone healing, pro-osteoblasts play a main role. Pro-osteoblasts originating from Haversian channels differentiate into osteoclasts and osteoblasts. Their function is removal of the necrotic bone and production of the new one.

In secondary bone healing, these pre-osteoblasts (osteoprogenitor) cells, deriving from the periosteum, differentiate into hondrocytes which produce fibrocartilaginous callus. This callus bridges fracture gap. It happens in avascular environment. Further on, in vascular environment, the inner layer of periosteal cells transforms into osteoblasts which then produce primary bone around callus. This bone is later replaced by the compact bone.

Osteoblasts actively participate formation of organic osseous matrix, through:

- alkaline phosphatase;
- mucopolysaccharides;
- osteocalcinin, which binds calcium;
- osteonectine which bind hydroxy-appatite for collagen and other enzymes;
- protein molecules, which present a base for later collagen fibrils, formed in the extracellular space.

Osteoblasts also play a role in calcium homeostasis, which, passing through membrane of osteocytes may accumulate or, if needed to release. [34, 38,50,62,70,57,70]

2. OSTEOCYTES

Origin from osteoblasts and are placed in beds, lacunas (lacunae osseae). Between osteocyte cell membrane and cavity all, there is a narrow space filled in by non-mineralized substance. It contains proteoglycogen, and this collagen microfibrils. (Fig. 1) Osteocytes assume pumpkin seed shape : looked from one side osteocytes are wide, oval; looked from the other side they are narrow. Osteocytes have many processes , reaching towards all directions and anastomosing at large scale. In younger zone, processes of neighboring cells mutually touch through ***ocludent zones or nexus***. They simultaneously bind with ostoblast on the surface into unique system. With aging, cells processes shorten, and neigh-

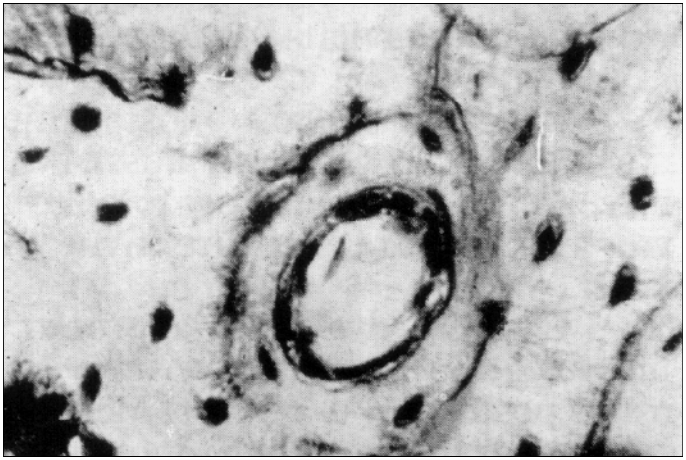


Fig. 1.

bouring cells are not interconnecsted. In comparison to osteoblat, ostecytes have less endoplasmatic reticulum, smaller Goldgy organels, less mitochondria, which indicate weakened proteosynthetic and secretory activity. Their main role is in maintaining homeostatic regulation of minerals, calcium and phosphate, first of all. They perform bone resorbtion and reparation in turn, do the transport between ions of tissue fluid, blood and mineral bone matrix.

It is proved that osteocytes contain acid hydrolases in lysosomes - enzyme responsible for disintegration of collagen fibrils and mucopolysaccharides of organic bone matrix. It also has moderate secretory activity of osteoblastic type. [34,38,50,52,62,70]

3. OSTEOCLASTS

Osteoclasts are giant cells with multiple nuclei, with bone resorption as a main role. The site of bone resorbtion may be noticed through presence of Howship lacuna, in form of half-spherical depression on bone surface, where osteoclast is placed. It is thought that osteoclasts produce organic acids (ascorbic, etc…) which then dissolve bone minerals. This exposes organic matrix to enzymes of ostyeoclasts. Lysosomes contain hydrolytic enzymes which degrade mucopolysaccharides and their products, while proteolitic enzymes degrade nucleic acids and collagen. Acid hydrolases, enzymes of osteoclasts, do de-polymerization of mucopolysaccharides; collagen fibrils become disorganized; gluing substance between fibrils is released. Following this cellular digestion, fragments of bone tissue are undergo fagocytosis done by osteoclasts. They can be found in their cytoplasm, in digestive vacuoles, where undergo intracellular digestion under the effect of lysosom's enzymes and acids.

Surface of osteoclastss, directed towards resorbing bone, is wrinkled due to presence of numerous invaginations of cell membrane. In cytoplasm, bellow this membranes, we find numerous resorbtive vacuoles and mineral deposits, as well as vacuoles indicating secretory activity. [32,48,52,60,70,72]

4. INTERCELLULAR BONE SUBSTANCE

Intercellular bone substance forms a main mass of osseous tissue and it is characterized with stiffness, hardness and elasticity. It contains organic and inorganic substances.

4.1 Organic composition of intercellular bone substance

Organic composition includes collagen fibrils and interfibrilar matrix.

Organic part account for 30 - 30 % of intercellular substance, called osteoid. Osteiod is composed of collagen fibrils and small quantities of albumin like and mucopolysaccharide gelatinous substance made of sulphuric proteoglycananans, containing chondroitin sulphate, keratan sulphate and hyaloronic acid. Distribution of collagen fibrils is condition by pressure forces.

Collagen molecules are produced in osteblasts cytoplasm and pushed out into extracellular space. In this space collagen produce pro-collagen. Collagen fibrils are produced by collagen polymerization. Fibrils further enmesh , building enmeshed chains. Synthesis of macromolecules of amino acids in osteoblasts is under the influence of: hormones (growth hormone, estrogen, testosterone), vitamin C and piezoelectric potential, with amplitude of several milivolts in long tubular bones. Bone diaphysis and cortex are electropositive , with difference to metaphysis and medullar cavity which are electronegative. In bone bending, concave side bearing maximal compression is electronegative and convex side is electropositive. In bone injury, elecronegativity increases on the injury site due to increased osteoblastic activity. It is thought that physical stress (walking, physical work, sports activities, sitting) applied to skeleton, a permanent regulator of the piezoelectric potential.

Interfibrilar matrix, composed of mucopolysaccharides and small quantity of interstitial fluid, is found in-between collagen fibrils. It is produced by osteoblasts, and pushed out into intercellular space where it build polymers. Concentration of mucopolysaccharid and protein complexes in bones is low (1 - 2 % of organic components of bone) ; biological significance is not well known. [32,38,42,54,60,70,73]

4.2 Inorganic composition of intercellular bone substance

Inorganic composition of intercellular bone substance is composed of mineral salts, which in bones assume the crystal form of hydroxyappatite. Calcium and phosphate are represented in 85 % of bone minerals, calcium carbonate, calcium chloride and magnesium sulfate are represented in 15 %. There is a minor quantity of potassium and sodium salts. All these salts (ions of calcium, phosphate and others) are deposed on fibrils surface, cover collagen fibrils of the bone. Bone mineralization happens at pH of 6 to 8, along with production with collagen fibrils. When fibrils interlace creating fibers, crystals are inserted within. Deposition is carried out only on certain places, creating crystal nuclei, "nucleus center" and process is called "nucleation" . Following formed core, other crystals deposit around. Ions, deposited on fibrils surfaces are free to move. They may circulate between bone, tissue fluid and blood. Ions which are inside fibers are separated from the tissue fluid and may follow metabolic changes only after enzymatic degradation of these fibers. [45,47]

Formed, mature bone tissue composes of organic part (25 %), which includes cells, collagen tissue, intercellular matix; inorganic part (67 %), composed of different mineral and water (8%).

5. HYSTOLOGICAL STRUCTURE OF BONE

Mature bone tissue appears inn two forms:
- cortical (compact, lamellar) and
- cancellous (trabecular, spounge)

5.1 Cortical bone

Main component of cortical bone is composed of lamellas, lined up next to each other, forming lamellar systems. Bone cells are interposed into inter-lamellar cavities. There is system of lamellas parallel to outer surface and another lamellar system parallel to inner bone surface. These are outer and inner basic or general lamellas. Between these two systems, we see many concentric systems of lamellas, surrounding Haverisan channels, stretching along the bone. Majority of osseous lamellas is placed concentric around Haversian channels and called Haversian lamellas. All lamellas around Haverisan channel form a bone unit called osteon. Space in-between osteons is filled in by irregularly placed osseous lamellas, which have no relation to blood vessels. These are transient or interstitial lamellas. Many of them developed from partially resorbed lamellas. Lamellas are made of fibrils, glued with interfibrilar mass. In one lamella they are mutually parallel, and perpendicular to those in other lamella. On bone cross-section, fibrils of one lamella are affected longitudinally, in the other perpendicularly. There is large number of small cavities (lacunae osseae) in matrix; osseous cells (osteocytes) are found there. Lacunae communicate through small channels, where extensions of the bone cell are placed. In youth, cells fill in lacuna completely, in elderly there is space between them and cavity walls. In long bones, Haverisan channels stretch longitudinally, in flat bones they stretch parallel to bone surface, holding arteries, veins, lymphatic vessels, nerves and some bone marrow. Channels connecting Haversian chanaalls are called Volkman's channels (Fig. 2) In some places, rough sheaf of collagen fibrils pass, from outer side of lamella. These are Sharoey's fibrils, stretching from the periosteum.

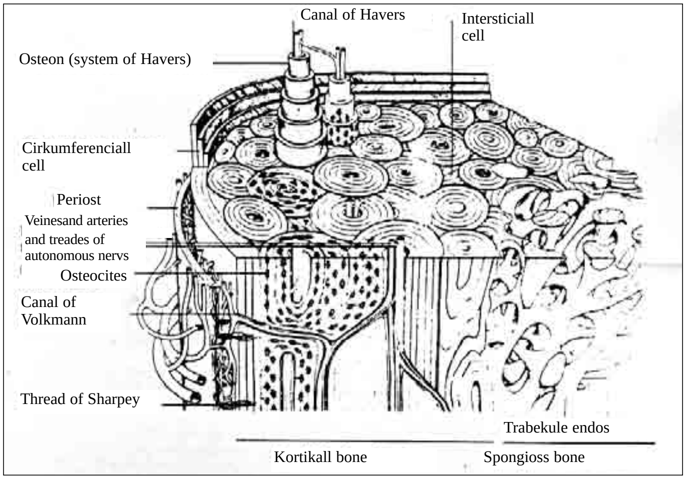


Fig. 2.

5.2 Cancellous bone

Cancellous or trabecullar bone is composed of osseous trabecules, which border a narrow space filled in by bone marrow. (Fig. 2) Trabecular thickness depends on number of lamellas which build them, and their distribution depend on pressure and Trabeculas are composed of two , three or more lamellar layers. They are placed in manner to bear forces they are exposed to. Next to cancellous bone trabecules, we find a line of osteoblasts, composing the inner bone layer - endosteum. Parts of skeleton required to be large and strong yet light are composed of cancellous bone. Cancellous bone tissue is commonly found in long bones epiphyses, then within short and flat bones. It has neither Haversian nor Volkman's channels, thus no blood vessels, since supplies pervade from the surface. Trabeculas which cross and close medullar cavities are filled in by bone marrow.

In diaaphyses of long bones, cancellous bone tissue is less present, so bone marrow fills in entire bone cavity. Bone marrow fills in medullar cavity in diaphyses of long bones as well s all spaces between bone trabeculas in the cancellous parts of bone. Bone marrow is chief organ for haemathopoesis.

5.3 Periosteum

bone tissues is embraced by cover - priosteum, thicker in children, thinner in adults. It is attached to the bone with Sharpey' fibrils, blood capillaries and nerves entering Haversian and Volkmaan's channels. It is composed of two layers:

a) superficial - thicker layer (stratum fibrosum) , mainly made of collagen fibrils, mixed with elastic fibrils, than lots of nerves, blood and lymphatic capillaries. Since it reaches Haversian and Volkman's channels, it nourishes bone and bone marrow.

b) deep - thinner layer (stratum germinativum) contains more cells; cells are placed immediately on bone surface with more cellular element, rare elastic.

Bellow this layer, we find layer of cells with osteogenic potential (stratum osteogenum subperiostale) . On adult bone these cells are inactive, but under special circumstances (during skeleton development phase and in bone damage) , they serve as reserve cells which transform into osteoblasts.

In growing bone, periosteum has slightly different structure; being composed of:

a) inner layer (caambium); non-compact, gentle structure, well vascularized layer of osteeoblastss;

b) middle layer; layer of undifferentiated osseous cells (osteoprogenitor cells)

c) outer, connective layer: composed of collagen fibrils, elastic fibrils, fibroblasts and numerous nerves and blood vessels .

Periousteum plays an important role in development, in bone ossification and bone regeneration.

Osteogenic potential of periosteal tissue during bone healing is related to several factors: mechanical load, perfusion, donor site, host site, combination with cancellous bone graft and salvage of subperiosteal cortical bone layer.

Following fracture, priosteum reacts with explosive mitosis of the inner cellular layer and gives rise to large number of osteoblasts, from previously determined cells. (24,34) Result is periosteal callus which first manages to bridge fracture gap. E. A. Tone and colleagues established periosteal activity after the fracture along the entire bone length, not only on the fracture site. (35)

Jaroma, in 1988, was first to describe effect of periosteum on cancellous bone graft. Cancellous bone graft, wrapped into periosteum and implanted into musscles would remodel into proper bone with cortex and medullar cavity in 20 weeks in rabbits. Cancellous graft alone would resorb. Romana, in 1989, reaches similar conclusion in rats; perfusioned periost without bone graft implanted into muscles would from thin bone by itself.

There is no periosteum on joint surfaces.

5.4. Endosteum

Wide medullar canal extends along diaphysis in long bones. Bone marrow in situated in it,. Bone marrow is separated from the bone tissue with thin connective tissue layer - endosteum. It is more dense fibrous layer of bone marrow, containing osseous pra-cells (osteeoprogenitor cells). Only under specific circumstances, endosteum produces bone tissue. In bone fracture, endosteal cells rapidly proliferate and form osteoblasts. Formation of internal, endosteal callus progresses more rapidly then formation of periosteal callus.

5.5 Medullar cavity

Medullar cavity is filled with bone marrow. With regard to appearance and structure, we distinguish three types of bone marrow: red, yellow and gelatinous.

After the fracture, cells proliferate in medullar cavity also. There are large number of fibroblasts and osteogenicc cells which play role in medullar callus formation.

6. BONE VASCULARISATION

Osseosu tissue is very rich in blood supply,; it has an extensive circulatory net which varies, not only in various bones, then among different parts of the same bone. Osteon possesses canaliculary system , necessary for substance exchange, interconnected with entire vascular system of the bone. In osteogenesis - blood vessels is organizer and initiator of complex pathophysiological processes within the fracture site. Endothelial cell, osteocytes and osteoclasts lie along normal line of bone formation and bone resorbtion. Blood vessels provide transudate , crucial for the life of entire syncicium. Anabolic and catabolic processes depend on bone vascularization. Every cell requires sufficient amount of oxygen and nutrient substances for its mitotic division and for physiological functions.(3) Process of bone formation and bone degradation happen more rapidly in parts vascularized better. (45,2,12)

"As better bone vascularization, that better fracture will heal, while reconstruction of any bone defect will be faster and more reliable" (12,17) - it is fundamental principle of bone vaacularization.

Works of J. Trueta (1960) and his followers proved that ostoblasts develop from the blood capillaries endothelium. Investigating osteognesis, his first conclusion was that blood vessels are directly responsible in the process of ossification. He could not accurately conclude about relation between osteoblasts and vascular cells. In experiments designed to follow on process of bone ossification, he chose the place close to metaphyseal plate; then arranged perfusion of blood vessels with fine barium solution. It was followed closely under electronic microscope. J. Trueta concludes: "There are no other sources for cells here illustrated, only vascular endothelial cells on their way to reside in the bone." (Fig. 3)

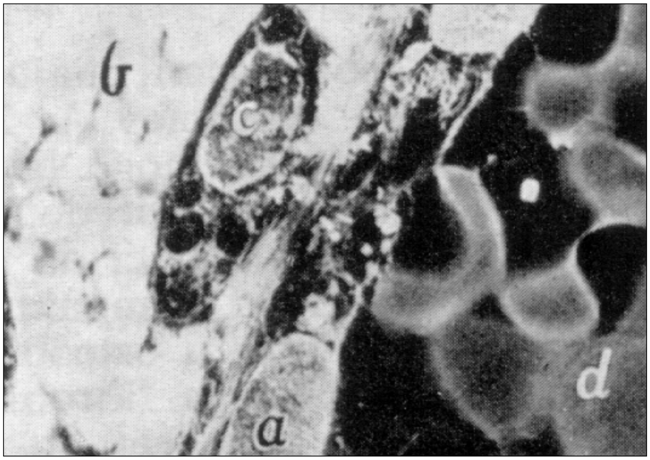


Fig. 3a - endothelial cell; b - bone; c - erythrocyte Original electronic microscope photography published by J. Trueta - 1961. (71)

6.1 Sources for long bone vascularization

Long bone vascularization is provided is provided by blood supply from the following blood vessels:

1. nutrient artery;
2. metaphyseal and epiphyseal nutrient aartery;
3. periosteal blood vessels.

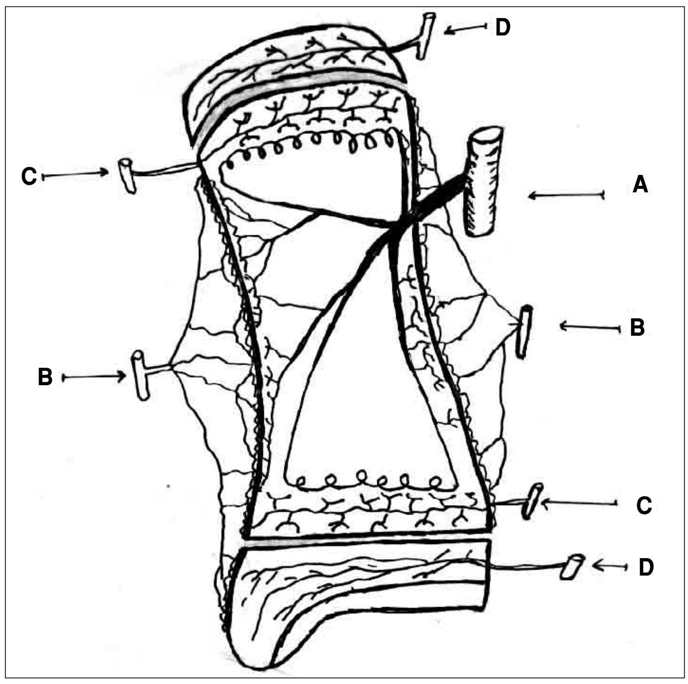
6.1.1. Nutrient artery

Every long bone has own nutrient artery and femur often has two. They are commonly collateral blood vessel to the main limb artery. Tibia has one nutrient artery formed, most often, from anterior branch of a. tibialis posterior, and penetrates tibia form posterior and lateral side, via nutrient hole. Through cortex, nutrient artery reaches medullar canal, branching into ascendant and descendent artery and anastomoses with perforate arteries of epiphysis and metaphysis. (sch.1)

Nutrient arteries are followed by two veins, of ten time larger caliber. From ascendant and descendent nutrient artery, small arterial branches develop, radially orientated, entering endostal cortex surface. They branch further and supply Haversian channels with blood. On their way through cortex, part of transversal blood vessels passes through Volkman channels and unites with periosteal blood vessels. In bone marrow a large system of sinusoidal vessels is formed , composed of arterial capillaries, which are long and straight, extending into wide venous capillaries. Venous capillaries drain into collateral sinuses, and those into central venous sinus. In physiological conditions, blood flow is centrifuge, or, from the medullar canal outwards. Nutrient arteries supply long bone with 50 - 70 % of blood.

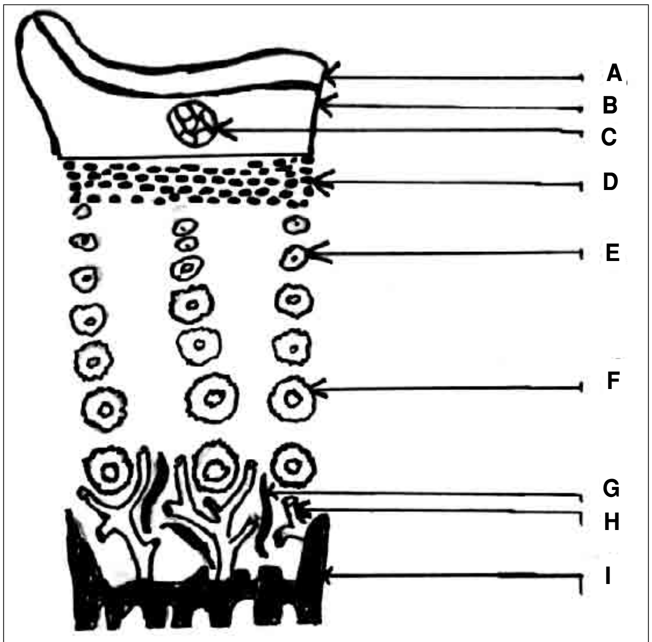
6.1.2. Perforate arteries of metaphysis and epiphysis

Until body growth cessation, epiphyseal and metaphyseal blood vessels are separated, with rare anastomoses. Trute (1959) proved that vascularity of long bones changes during the child's development. Blood vessels which as a terminal branches of nutrient artery reach metaphysis and plate of growth, bend in arch in order to reach great sinusoid veins. Plate of growth is a



Shema 1. A - nutriciona arterija, B - periostalne arterije, C - metafizarne arterije, D - epifizarne arterije

mechanical obstacle to anastomosis between epiphyseal and metaphyseal circulation. Injury to epiphyseal cartilage is very important since the process of growth takes place in that region. An epiphyseal injury usually understands injury to epiphyseal plate - germinate layer. Epiphysis (B) is an extended bone end, found between joint and epiphyseal cartilage plate (Sch 2). It is covered by joint cartilage (perihondriuma -A), through which is supplied by blood. Secondary centers of ossification (C) are found in epiphysis at different ages. In some bones, they are present upon birth, in some bones they are absent in eight - ninth year of life. Next to epiphysis is zone of compact cartilaginous cells (D). These cells aare inactive and present reservoir for future mature cartilaginous cells. Towards diaphysis, these cells show signs of active growth. Become augmented, lined up in regular vertical columns towards metaphysis, with plenty of extracellular matrix.[23,34] This is a zone of growth (germinate layer - E) of epipyseal plate. As closer to metaphysis, so more cells hypertrophy is present, and in the next layer they pass into a degeneration phase, as well as extracellular matrix (F). This is zone of cartilage degeneration, followed by zone of primary enhondral ossification (G). Capillaries (H) grow into it from metaphyseal arteries, osteoblasts line up along (I). [23,34,56]



Shema 2.

Cartilaginous tissue resorbs on account of newly formed, osseous tissue. Process of cartilaginous cells development is adequate to the primary ossification on metaphyseal part of epiphyseal plate. When cartilaginous plate reaches metaphysis, transformation of cartilaginous tissue into osseous tissue is completed.

From metaphyseal area, epiphysis remains protected by wide plate of growth , efficient in guarding joint space and it explains rare joint infections in children. Trueta (1955) in its study established that plate of growths is noticeable in infant age from the sixth months on, and definitively shaped around eighteenth month of life. From epiphyseal cartilaginous plate, bone grows into length. As vascular anatomy is concerned, infant bones grow into a child' bone at one year of age. In infantile period , blood vessels from metaphysis penetrate through plate of growth and reach epiphysis and joint space.

In metaphyseal blood vessels injury, there are usually no consequences for the further growth. Growth is temporarily impeded and rapid recovery follows reduction.

If epiphyseal blood vessels are injured, there is a permanent damage to bone growth. Aseptic necrosis with deformation of joint surface will develop. Traumatic epiphyseolysis takes place in anatomical weakest layers, in zones of cartilagineous cells degeneration and in zone of primary enhondral ossification. Real epiphyseolyis is caused by shear forces, to which perichondrim is less resilient,. Epiphyeal cartilage (germinate layer) allows for interrupted circulation to revive soon via, diaphyseal blood vessels. Even dough dislocation may be large, if adequate reduction and stabilization are performed in time, such injuries rarely create serious problems with regard to bone growth and shape, since bones remodel well.

Injury to diaphyseal blood vessels may provoke collateral hyperemia in epiphyseal zone of growth and accelerate bone growth, until the normal circulation in diaaphyiss is re-established.

When growth terminates, metaphyseal, epiphyseal arteries confluent with nutrient artery, creating a unit, in comprehensive bone circulation. They form a vascular net of medullar canal, supplying two thirds of inner cortical layer. Participate long bone vascularization for about 20 - 30%.

6.1.3. Periosteal blood vessels

Periosteal blood vessels penetrate periosteum and form a vascular pedicle, supplying the outer third of cortex. These arteries origin from local muscle artery. System is also connected with system comprising of nutrient artery and metaphyseal and ephyseal perforate arteries. In some segment, blood vessels net is insufficient (tibia on connection between middle and lower third), where bone fracture may be associated with interruption of nutrient artery and muscle detachments. Periosteal circulation alone may preclude delayed union or pseudoarthrosis. Periosteal circulation alone is insufficient to supply cortex , while medullar blood supply may take over the complete nutrition of cortex. [72] If bone fragments are stabilized with AO plate and Kuncher nail, dominant medullar system will be established through nutrient vessels in 14 days, as average. With periostal stripping, due to absence of periosteal circulation, necrosis occurs on the cortex, reaching half way of cortex.

After fracture, in the inflammatory phase, blood vessels proliferate and periosteal circulation is first to react. It provide blood supply for peripheral or periosteal callus. Medullar circulation is impaired in both fracture fragments. In the beginning, medullar circulation is blocked by haemathoma, and cortex mainly supplies via priosteal blood vessels.

Rinelander (1968) , in his experimental works followed on circulation evolution in the process of bone consolidation. In five months following fracture, periosteal circulation normalizes, while medullar is still enhanced, to stimulate bone remodeling phase. Conclusion of these works is that endosteal blood supply has a greater and dominant role over the periosteal circulation.

6.2. Mechanism of blood circulation in bones

Blood flow through a vascular net is constant. Hearth pump provides continuous blood flow in organism. Its effect on blood flow in bones is minor due at blood pressure drop in veins leaving the bone while sinusoids between arterioles and veins are in firm chambers of bone marrow. Among all mechanisms, continual contraction of muscles attached to the bone is the most important. Muscle contractility has a positive effect to sinusoidal flow, and improves venous circulation also. [36,37]

Thus, in bone fractures, isometric muscle contractions should start , as soon as the pain ceases.

II - WAR WOUND

1. HISTORY OF THE WAR WOUND TREATMENT

Even in the early phase of its development man was resolving conflicts by use of force - fists, teeth, stone. With time, weapons were being developed - knifes, swords, bow and arrow. Man has discovered that enemy can be injured and defeated from a distance as well. (67) Discovery of gunpowder and firearm led to further expansion in both development and production of the explosive devices and in methods of combat.

In history of medicine, the very first hint about specific features and required treatments of the war wound caused by small projectiles fired from the firearms, originates from the article titled "Bundit-Erzney" written in 1460 by Henrich Von Pfolspound. (67)

Ever since the antipersonnel firearm was found, somewhere in the mid of XIV century, up today, military and medicine are caught in dead run. Military objective is to develop weapon for human mass injuries and to cause as much as possible of human suffering; medicine is after prevention and protection of human lives.

Based on mortality rate in previous wars, medicine is in constant progress.

Analyzing mortality in Homer's Iliad, German researcher Freilich concludes that among 147 injured with knife, sword and spears, 114 injured people died. Accordingly, mortality rate was 80 %. Twenty eight centuries later, according to the report of Napoleon's chief surgeon Jean-Dominique Larrey, mortality rate among wounded is decreased for 50 %. In 1814 he reports on 13 000 of deaths among 45 000 of wounded. Consequently, mortality rate was 28,8 % . (67)

Decrease of the mortality rate is due to extreme efforts of all surgeons treating wounded throughout numerous wars in the human history. Their commitment to the life, their courage despite odds, led to a progress in knowledge possessed by human kind.

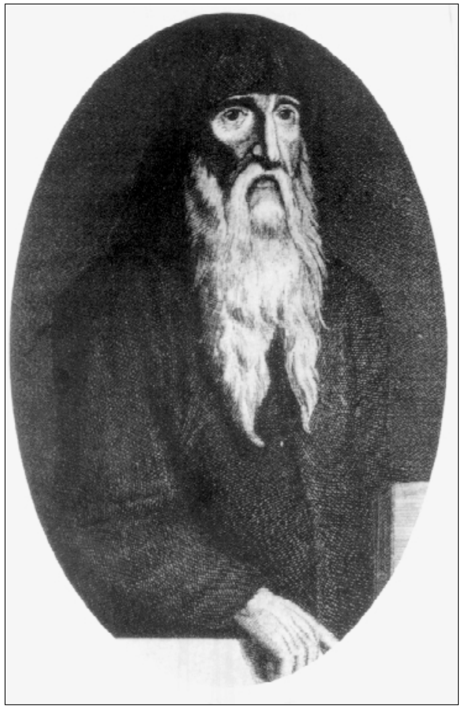


Fig. 4.

Hypocrites, 446 BC, son of a doctor and one of the earliest western medicine doctors (Fig. 4) based his approaches following own observations mainly. Hypocrites findings and observations influenced development of all medicine. Many comments and notes Hypocrites left behind are valuable even today and truly, Hypocrites is one of the most genius doctors in the history of the human kind.

Galleons (Galleons) , 130 BC says that suppuration is important and desirable and recommends application of different chemical substances into the wound. Celsius, 25 BC introduces ligatures of the blood vessels as well as amputations of limbs using circular cut in one plane, named after him.

Hugo de Luke, surgeon from Crusade wars, in 1206 and his son Teodorik, in 1298, oppose illusions about suppuration and puss as a salvage. They stand for and promote "dry" treatments, trying to avoid suppuration of the wound, claming it as a fatal. Guy de Cholaux in 1345 recognizes the need for active approach to the wound, in terms of cauterization. This attitude is confirmed by Giovanni Vigo and Alfonso Ferri in the year of 1544. They postulated that wound sustained by firearm, contaminated by gunpowder, should be burned with hot iron. Paracelzius , in 1538 raises his voice against cauterization of the war wound and claims that wound should heal per primam. Paracelzius does not accept active surgical management.

Starting as a barber, having no knowledge on Latin language, Amboas Pare became most impressive surgeon of his epoch and one of the greatest surgeons in human history. Being ignorant in Latin language, he did not rely on interpretation of the old papers. Instead, he acted following own findings and observations. In 1545, in French, he publishes his work, re-introducing ligature of blood vessels (forgotten after Celsius), limb amputation up to the healthy, viable tissue, limbs ligature as a hemostasis mean and anesthesia during performance of limb amputations. In the same paper he gives up treatment of the wound with hot oil.

Ledrane, French surgeon form the XVII century is a classic representative of the active and operative surgical attitude in the war wound management. The term "debridement preventif" is introduced by his younger colleague, Desole, who lived in XVIII century. "Debridement preventif" understands cutting along the missile track and removal of loose bone fragments and foreign bodies. Desole introduces wound excision and strongly promotes an early amputation.

Consistent promoters of the French surgical school are Napoleon's surgeons Persi (1754-1825) and Larrey (1768-1842) who successfully organize first surgical aid: carriers of the wounded, ambulances, first mobile filed hospitals. Larrey demands that primary surgical treatment of the wound is performed as soon as, then applies occlusive bandages and opposes frequent wound redressings. Three times being wounded himself, he advocates active surgical approach , particularly with regard to the primary amputations. During battle near Borodine he, himself, performed 200 amputations within 24 hours. Greatest English surgeon, Gatry, (English Larey) was his contemporary colleague and sincere follower.

Dominance of this school was present in Europe until the second half of the World War II.

Pirogov (1810-1881) has an salvaging attitude to the wounded limb. He applies fixation cast bandage which, in majority of cases replaces primary amputation. During transportation of wounded, Pirogov applies cast bandage in open and closed wounds of the limbs but does not perform primary surgical treatment of the wound. Also, Pirogovov was the first who introduced narcosis with ether on the battle field (1947), he developed the casting technique and significantly contributed to the health care service organization - triage, transportation of wounded, data collection, medical records and nursing care.

Fig. 5.

German Esmarch, working on existing methods introduces "first aid bandage", method of the artificial hemostasis with elastic band called Escmarch - new band.

Work of Pasteur and Lord Lister (Fig. 5) from the end of 19th century allow triumph upon infection and American dentist Norton solves the anesthesia problem. Lord Lister, in 1867, reports on primary healing of the open fracture of tibia. This undertaking is made possible by new procedure whereby carbonic acid is used as an antiseptic.

In the end of 19th century, Ernest Bergman claims that war wound can be considered aseptic and consequently that infection secondary in origin. Wound should not handled; destiny of it is determined by aseptic bandage and bedrest. Bone and joint fractures should be covered with sterile bandage, immobilized by cast and if infection occurs, resection, not at all amputation, should be performed. He experiences failed attempts of antisepsis with Lister's spray and realizes that frontline dressings are far from the clinic setting.

Fig. 6.

With animal experiments, in 1898**, Fridrich** proves the following :

1. within first 6 - 8 hours following injury, germs are to be found in the wound not deeper than 1 - 2 mm and only after incubation of 6 and more hours germs are found in deeper layers;

2. cutting the wound in toto, comparably to the tumor resection, wound can be sterilized.

Despite all knowledge, conservative Bergman's doctrine dominates outset of the World War I. Based on gained experience, Surgical Congress, held in 1915, in Brussels and Paris stands for the more active approach in the war wound management.

Great Spanish orthopedic surgeon, **J. Truete**, uses experiences acquired in Spanish Civil war in common practice : he performs **radical primary treatment of the war wound**, followed by immobilization of the injured limb with closed cast . With such procedure, he achieves immobilization, protection from subsequent infection and drainage. In the year of 1939 he established ten postulates of the war wound treatment [74,75]: **classification, resuscitation, an early surgery, immobilization and early mobilization**. In the course of surgery he uses: **irrigation, incision, excision of the dead tissue, no suture, drainage and stabilization of the bone fragments (cast)**. Such surgical approach finds strong support in antibiotic administration and gives treatment base for the gunshot wounds in the World War II.

Sulfonamides are administered locally and generally. Discovery of the Penicillin (Sir Alexander Flaming) and its extensive use dating from the 8th November 1942 greatly improves treatment outcomes.

In Serbian history of medicine, first respectable paper is written by Vladan Djordjevich (Fig. 6), Bilroth's student, founder of the Serbian Red Cross and Serbian Medical Association . Based on experience gained in Europe, being participant in three wars, he establishes organization of the health care in Serbia. Mihajlo Markovich contributed to the organization of the health care services as well as to the organization of good surgical care in the wartime. Organization of the health care in the war time was a pleasant surprise for the European missions visiting Serbia in the World War I. Nikola Krstich (Fig. 7), founder of the Serbian orthopedic surgery and Jordan Stajich, "Serbian Larrey" have also given significant contributions.

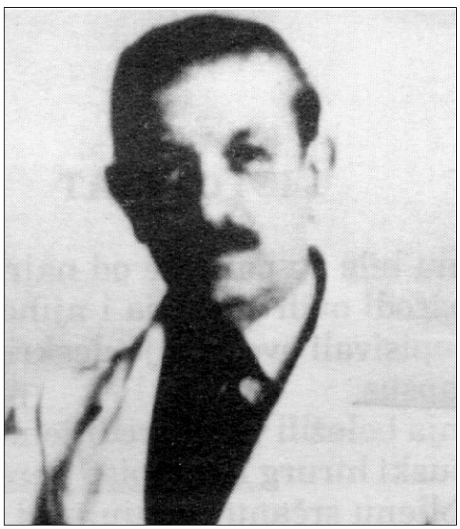


Fig. 7.

1.1. War wound

A war wound caused by firearm in the war-time is an injury to a body characterized by extensive tissue destruction, primary polymicrobial contamination and with change of bodily response to injury.

Fig. 8 a

Fig. 8 b

respect for the chief principles. Following the principles of peace wound management when dealing with war wound can lead to a disastrous consequences.

Injuries are mainly limb injuries (about 40 %) . Out of this number, in average , 40 % is followed by bone fractures. (15, 17, 34, 56, 78)

At Banjaluka Hospital, Department for the Orthopedic Surgery and Traumatology, in the period from 15th of September of 1991 to 1st of December of 1995, we treated 2462 war wounded - limb injuries, multiple abdominal injuries, thoracic injuries and head injuries. In 256 wounded (10 %) we were to deal (primary surgical treatment) with musculo-cutaneous limb injuries. Among 2197 wounded who sustained bone injuries, there were 2034 (92, 43 %) with comminutive bone fractures, with or without bone loss. Such injuries are results of the new weaponry developments. Objectives in treatment of the gunshot limb injuries are not only to salvage the life and the limb, then attempts are made to restore limb function entirely, in the shortest time possible.

War wounds are caused by projectiles from the firearm; by bullets from the antipersonnel weapon or by the piece of explosive device. [32, 33, 34] (Fig. 8a - prior to primary surgical wound management ; Fig. 8b - following primary surgical wound management).

In comparison to a peace time wound (projectile of low initial velocity) and to the open fractures, gunshot wounds are associated with greater bacterial contamination as well as extensive damage to soft and osseous tissue. Thus, war wound is a distinct entity and subject of interest even today.

Gunshot injuries in war wound are consequence of disruptive projectile forces as such and subsequent destruction of the tissue (organs) and forces of tissue (organ) resistance. By intensity, disruptive forces destroy continuity of the affected tissue. War wounds are typically caused by missiles of high initial velocity, which cause injuries which differ from the peace-time injury and thus require specific management. Management of the war wound understands adequate staff training and

2. MISSILE BALLISTICS

Ballistic is the study of projectiles through barrel, air and tissue. **Silliphant** distinguishes the following:

1. **internal ballistics** or barrel phenomenon;

2. external ballistics or projectile motion through the air;

3. terminal ballistics o projectile penetration in tissue.

Projectile movement through the barrel are more concern of the arms manufacturer and military experts.

2.1. Phenomena of the projective motion through the air

Projectile movement through air depends on its initial velocity and on the number of rotations around its longitudinal axis [32, 33,34,35,35]. If the missile cones moves 900 meters per second it may reach 200.000 rotations per minute, around its longitudinal axis. When a missile loses its kinetic energy as ricochet or rebound, then the spin induces variations in motion of projectile e.g. precession and nutation. Such projectile causes greater destruction due to increased contact surface between the missile and the tissue. Unstable missile of the same mass and velocity always conveys more kinetic energy and causes greater destruction. This has been observed long ago and in 1874 Brussels Declaration prohibits the use of such weapon which can cause severe injuries. One of the conclusions of the Symposium on ballistic of the war wound, held in Lucerne in 1974, is that initial velocity of the missile is much more relevant for its kinetic energy then its caliber. When a projectile ceases in the body , the quantity of the kinetic energy which is transferred to a tissue equals to the total kinetic energy of the missile. It is proved that faster and smaller projectiles can cause shallow wounds with more extensive destruction. This happens due to increase of resistance coefficient occurring when projectile moves through the body with speed above 1500 meters per second.

According to the velocity (which correlates with severity of the wound) we distinguish:

- low initial velocity up to 360 meters per second;
- mid velocity, between 360 and 750 meters per second and
- high velocity , over 750 meters per second.

Pieces of the explosive weapons can reach initial velocity of 3000 meters per second; they are usually irregular in size and of grater mass. In most of conventional wars injuries caused by shrapnel or fragments of the explosive weapons are most common. There are two types of explosive devices:

- old type;
- new type.

Old type of the fragments is result of explosion and scattering of metal jacket in grenades and bombs of big caliber. In this type, fragmentation as such produces projectiles of different sizes, which are deformed and weight about 20 grams. Due to irregular shape their velocity decreases rapidly, despite the fact that their initial velocity can be over 1500 meters per second. [35, 36, 37, 40, 55,70].

Fragments of newer generation are those fragments which weight between 0,1 to 0,2 grams, have 2 to 3 mm in radius and whose initial velocity of 1500 meters per second does not decrease rapidly. Prior incorporation into explosive device, they are usually made regular in shape. [67].

2.1.1. Missiles of low initial velocity

Projectiles of low initial velocity, about 150 to 250 meters per second are stable, usually resulting from a gun or from the old generation firearm. Due to a short track such projectiles utilize only 10 to 20 percent of their blow energy when causing the wound, transferring kinetic energy to a tissue. [23, 25, 27]. Such injuries are most commonly seen in peace time. In such injuries there is no temporary cavity, then residual missile track, which corresponds to a muscle and soft tissue damage. [17, 19, 27].

With penetration of the projectile, tissues become separated, torn and injury is not severe unless vitals organs are damaged. Projectile damages tissue in direct contact, wound can be compared with the knife stab. Small kinetic energy is transferred to surrounding tissue and destruction we observe during primary surgical wound management is the total damage. [17, 56, 37]. With regard to the minimal damage to the bone and soft tissue, treatment outcome is much more favorable and likelihood for complication development is less, in comparison to a wound caused by projectile of high initial velocity. [67]

Leffers compared a serial of 40 case injuries caused by low velocity projectiles with peace -time open fractures and concluded that classification of the open fractures, in relation to the extent of soft tissue damage, corresponds to the Type I group of fractures. [46, 47] Along with a less extensive destruction of the soft tissues there is a less extensive destruction of the bone, with specific fragmentation shape: oblique, spiral, perforate, comminutive with "butterfly" fragment. [17,23,67]

2.1.2. Missiles of high initial velocity

Today, vast majority of weapons fires projectiles of high initial velocity . The wound caused by such projectile completely differs, in extent and quality of the tissue damage, from the wound sustained with projectiles of low initial velocity. One of the features of the projectiles with small mass and high initial velocity is that they can scatter or fragment into pieces during tissue penetration. For this reason outside appearance of the wound can give a false impression since small entry or exit wound can be associated with enormous internal destruction. Motion of the projectile through the air, and then within a tissue depends on size, shape, type of the tissue as well as its stability and velocity. With penetration of projectile through tissue projectile is slowed down, due to a density of the penetrated tissue. Soft tissue is , in average, between 800 and 900 times more dense then the air and penetration through the soft tissue makes projectile unstable. Stability decreases with trajectory length. Rotation and fragmentation of the projectile take place along with greater destruction.

Stable projectile passing through the tissue produces missile track, transferring 20 to 30 % of its energy. The very same unstable projectile, when penetrating, transfers 60 to 70 % of own energy. [14, 23]. Power of the projectile in producing a wound depends on the kinetic energy which is transferred when projectile hit and moves through the tissue. [67, 45] With direct impact (physical) projectile causes tissue destruction, tearing and contusion, while via indirect impact it causes phenomenon of the shock wave and temporary cavity effect. Shock wave occurs immediately upon contact of the projectile and tissue, it is of short duration, 15 to 20 milliseconds. Only projectile with velocity above velocity of sound can produce a shock wave. [70, 72, 75]

Conventional anti-personal weapons have a cones missile, surrounded by a hard metal jacket (most commonly copper) which tends to retain its initial shape. Due to aerodynamic shape, there are minor disturbances during the air motion and a minor velocity loss. This is obvious on the tissue - projectile produces regular, cylindrical, narrow missile track. Such path starts changing shape with destabilization, deformation, change in direction or with fragmentation of the projectile occurs. There is usually double cavity with longer "neck of the wound", occurring due to destabilization of the projectile following precession and nutation of the projectile.

Dumdum bullets have an uncovered lead tip without metal jacket. Used in India, this type of bullet is today incorporated into standard weapons 7,62 (NATO) and 5,56 (US M. 193.). In comparison to 5,56 mm projectile, the missile 7, 62 produces long-neck, cylindrical or cones missile track, due to grater mass and lower velocity , pass through the tissue "more calmly", penetrates deeper and releases less energy continuously, along the track. Projectile 5,56, in comparison to the projectile 7,62 has a lower mass and greater velocity, losses stability and fragments immediately upon tissue penetration. Energy is rapidly given to the tissue, producing a tubular cavity with a short neck, and excessive defect wound channel along with extensive destruction. Such projectiles injure blood vessels and nerves more often. Due to elasticity blood vessels have better tolerance to the temporary cavity then the other soft tissues. Penetrating through more dense tissue, it releases energy more rapidly. Such projectile produces penetration track 40 times larger in volume then a conventional missile of the same weight and velocity.

With penetration of projectile through the tissue, projectile velocity decreases but kinetic energy which projectile gives to the tissue produces damage. Lately, term "energy deposit" is used more and more to indicate extent of the kinetic energy tissue destruction. Absorbed energy is directly proportional to the specific gravity and density of the tissue. Tissues of higher specific gravity suffer more sever destruction - bones, muscles, parenhime organs. It is noticed that the same amount of energy released into muscle tissue causes greater destruction in places of greater muscle mass. The specific gravity of some tissues is as follows:

• lungs	0,4 g/ml
• adipose tissue	0,8 g/ml
• liver	1,02 g/ml
• muscle	1,04 g/ml
• skin	1,09 g/ml
• bone	1,11 g/ml

This is the reason for more energy being transferred to the bones then to the lungs. Albrecht and others with their experiments proved that destruction extent depends on ballistic features: amount of the given kinetic energy, precession of the projectile and fragmentation. (33, 35, 70, 72)

3. MORPHOLOGY OF THE WAR WOUND

Features of the war wound, apart from motion of the projectile through the wound, depend also on the missile shape, weight and material; on stability, angle of inclination, velocity, mass and specific gravity of the injured tissue or organ, then on distance between the body and the weapons.

Kinetic energy (live force) of the fragment or shell is proportional to its mass and velocity and it is calculated by the following formula:

$K= MV^2/2$

By transferring kinetic energy to the tissue, velocity of the projectile decreases during penetration . Transferred kinetic energy is used for tissue destruction and it defines the extent of the tissue damage. Kinetic energy is proportional to the specific gravity and to the density of tissue, and transferred energy , and greater destruction will occur on bone and muscle tissue then on lungs. Brain is most sensitive to the temporary cavity.

The ballistics of the wound studies the motion of the missile through the human body and consequent formation of the missile track. Mechanism of tissue injury and the formation of the bullet track are explained by the impact of the missile on its path through the tissue and with production of the lateral blow into the tissue. Irregular projectiles cause maximal destruction at the start of penetration. Later on, there is a gradual decrease in distention of the temporary cavity. [38, 18, 78]

Aerodynamic projectile causes minimal disruptions but following penetration into tissue there is deformation, fragmentation or ricochet and consequent increased tissue disruption. [78, 18].

3.1 Classification of the war wound

Regardless numerous attempts to establish war wounds classification, in order to facilitate scientific evaluation of the surgical treatment, there is no widely accepted classification.

Based on the entry, skin wound, there are:

a-vulnus punctiformis ("punctate wound") , is either oval or round, sharp-edged and with a narrow bullet track. A shrapnel or tinny missile penetrates deep into a tissue, producing a deep track and extensive damage. The missile track is very narrow.

b-vulnus sulciformis ("groove wound") is result of tangential contact of the missile with the tissue and it is groove-like shaped. It impacts on soft tissue surface while it does not cause serious complications on injured limbs. The wound is fully accessible.

c-vulnus foraminoformis ("foraminal wound") has larger entry hole. It is irregular in shape, with notched margins. The tissue is grossly damaged and the bullet track is irregular.

d-vulnus crateriformis ("crater wound") is large, irregular cavity with notched margins which extends to a long bullet track, surrounded by extensively damaged tissue. Usually, there are pieces of boots, clothes and dirt to be found in the wound.

e-vulnus contusum laceratum explosivum is a lacerated, perforated, crater-like wound associated with a gross tissue defects and irregular edges. Pieces of clothes and dirt may be found in the wound.

f-vulnus contusoconquasatum is wound sustained by a projectile of great initial velocity and mass, with irregular edges and followed by extensive loss of tissue.

Classification of the open fractures by Gustilo-Andersen; Muller et al.; Tscheme Oestemu (which consider damage of the soft tissue as well), does not present comprehensive classification of all war wounds of the locomotor system.

The Red Cross (1991) wound classification is a system whereby certain features of the wound are scored. The limitations of the scoring are recognized; complete accuracy can not be obtained. It should be emphasized that the scoring is for the rapid use under adverse conditions.

The scoring system classifies the war wound considering the following elements:

1. E = (entry) centimeters - Estimate the maximum diameter of the entry

2. X = (exit) centimeters - Estimate the maximum diameter of the exit (X=0 if no exit)

3. C = (cavity) - Can the "cavity" of the wound take 2 fingers before surgery? No: C=0; Yes:C=1 ; This may be obvious before operation or only established after skin incision. For chest and abdominal wounds it refers to the wound of the chest or abdominal wall.

4. F = (fracture) No fracture: F=0; Simple fracture, hole or insignificant comminution: F=1. Clinically significant comminution : F=2.

5. V = (vital structure) Are brain, viscera (breach or dure, pleura or peritoneum) or major vessels injured? No: V=0. Yes: V=1.

6. M = (metallic body) Bullet or fragments visible on X-ray. Non: M = 0; One metallic body: M = 1; Multiple metallic bodies: M = 2.

Subsequent analysis

Wounds can be graded 1,2 and 3 from the E,X,C and F scores.

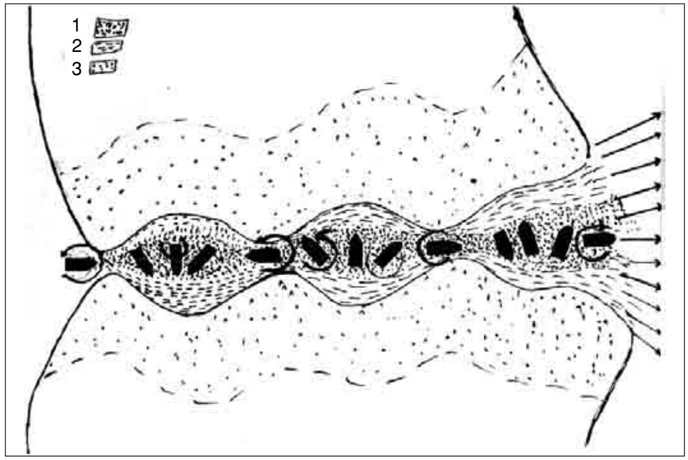
GRADE 1 : Wounds where E plus X is less than 10 with scores C 0 and F 0 or F 1 (low energy transfer)

GRADE 2 : Wounds where E plus X is less than 10 with scores C 1 or F 2 (high energy transfer)

GRADE 3 : Wounds where E plus X is 10 or more with scores C 1 or F 2 (massive wounds)

Typing the wound according to structures injured:

Type **ST** - wound with F=0 and V=0 (soft tissue damage)



Shema 3.

Type **F** - wound with F=1; F=2 and V=0;
Type **V** - wound with F=0 and V=1;
Type **VF** - wound with F=1; F=2 and V=1

By grading and typing war wound is classified in 12 categories:

	Grade 1	Grade 2	Grade 3
Type ST	Small, simple wounds	2 ST	ST
Type F	1 F	2 F	3 F
Type V	1 V	2 V	3 V
Type VF	1 VF	2 VF	Large wounds threatening life or limb

3.2 Missile track

Missile track is being formed with penetration of the projectile through the tissue (Sch.3). Within a missile track we find three zones which differ in pathology and morphology.

1. central zone
2. zone of massive blow
3. zone of molecular blow

3.2.1. Central zone

Central zone (zone of direct traumatic necrosis) is shown with a bullet track, which is result of direct tissue and organs destruction, caused by projectile as a physical agents. Traumatic necrosis is immediately present. Due to release of kinetic energy at penetration of projectile through the tissue, temporary cavity occurs and spreads as a pulsating wave, pressing on tissue and squashing it. Developing blow wave throws tissue anterior, lateral and backwards. Immediately upon crush of the projectile of high initial velocity there is shock wave, short in duration, 15 to 20 milliseconds. The life of temporary cavity is but a few milliseconds and developed cavity is 30 to 50 times bigger then the central missile track. The pulsating frequency is around 1600 to 2000 m/s. During pulsation of temporary cavity, positive and negative pressures develop in turns, associated with suction of the air and foreign bodies and consequent primary contamination of the war wound. Fragments of the broken bones, acting as a secondary projectiles in the wound, contribute to the temporary cavity formation and to the extent of the local destruction. During the period of the primary cavity expansion negative pressure of 1 atmosphere arises. When temporary cavity collapses, there is a positive pressure of 4-5 atmosphere. This sub-atmospheric pressure within the temporary cavity allows detritus to be sucked into the wound (bacteria - via entry and exit wound caused by the projectile).With collapse of the temporary cavity, air with bacteria and detritus is squeezed into the molecular injury zone of the wound. Intensity of pulsation weakens, eventually ceases, leaving missile track behind.

Apart form the initial velocity, size of the temporary cavity depends on:

1. deformation of the projectile;
2. fragmentation of the projectile following contact with a body;
3. longitudinal axis of the projectile and contact angle between the body area and most of the projectile surface;
4. anatomical region which is affected.

3.2.2. Zone of massive blow

The zone of the massive blow occurs around the missile track, it is extension to the previous zone and it is variable in size. Within the zone of the massive blow, tissue is irreversibly destroyed and liable to necrosis. Necrosis develops within few hours following injury.

3.2.3 Zone of molecular blow

The zone of molecular injury, or so-called extravasation zone, is most peripheral zone characterized by temporary ischaemia due to a spasm of blood vessels. First, there is spasm, then dilatation of blood vessels, and increased capillary permeability followed by traumatic edema. Consequence of these events is diminished, poor circulation in tissues and organs which may lead to irreversible changes. Often, there are cracks within this zone, communicating with missile track and allowing for spread of infection and greater tissue necrosis.

Border between the second and third zone is indistinct, even to a most experienced surgeon. Recovery of circulation in the zone of massive blow shifts this zone towards the zone of molecular injury. In case of repeated injury, the opposite happens.

III - TREATMENT OF THE OPEN WOUNDS OF LIMBS

If a correct and timely surgical management of the war wound is performed within six hours from injury, the prognosis is better, there will be less disability, fewer surgical re-interventions and less complications. Such management decreases load of work for the surgical team. With primary treatment we prevent high-molecular proteins disintegration and development of the bacteria in the war wound.

1.1. Wound cleansing

The limb should be shaved. Using sterile brush and saline or 3% hydrogen or povidone iodine the limb should be washed and cleaned of dirt and dry blood. When washing one should be careful not to contaminate the wound further. The wound should be covered with sterile gauze or close with Mishel's clamps backhouse. The wound should be profusely lavaged with saline, cleaned and check for all foreign bodies (pieces of clothes, dirt, blood cloths).Change gloves after cleaning, drape and prepare the operating field in classical manner.

1.2. Primary surgical management of the wound

Primary surgical management of the wound is treatment of choice for the war wound and it requires an active attitude and participation from the surgeon throughout the entire operation.

One must not overlook even the smallness puncture wound as it could have disastrous consequences (e.g. gas gangrene).

Gunshot wound caused by projectiles of high initial velocity are followed by extensive tissue destruction. Such wounds require more radical surgical treatment, thorough exploration of the missile track and removal of all de-vitalized tissue structures. [13, 24,70]

Best prevention of war wounds infection includes generous lavage, elimination of pockets and dead spaces filled with fluid-or blood cloths which present are an excellent ground for bacterial growth. In such injuries most of the authors recommend re-debridement of the wound within 24 to 48 hours. Namely, it is difficult to assess vitality of the tissue during the primary debridement. [51, 67, 59]

In his experimental works Albrecht has found that local administration of antibiotic within three hours following injury allows delay of primary surgical treatment of the wound up to 72 hours, with no increase in infection rate. During the Falkland war Jackson came to a similar conclusion. He would start antibiotic therapy within a period of 6 hours. [70, 76] Results shown that if antibiotics were administered within three hours following injury there were no septic complications, due to inhibitory impact on the bacterial growth in gunshot wound.

Experiences from the recent war in Croatian and Bosnia and Herzegovina confirmed necessity of establishment of the venous line and administration of the i.v. fluids with antibiotics, immediately after the incident occurred and after the first aid was given.

Such procedure support viable venous line which is much more difficult to establish and sustain in case of profuse bleeding and venous circulation collapse. Antibiotic administered along with an i.v. fluid is effective towards bacteria and viruses which primarily contaminate war wound.

Skin is very resistant to damage and it is only necessary to perform sharp debridement one millimeter into a viable skin. When treating skin do bear in mind that there will be delayed closure. One must adapt the incision and excision to the Langer's lines. The debridement of the skin and subcutaneous tissue should be carefully performed , removing blood cloths, foreign bodies and non-viable subcutaneous tissue.

The viability of the skin can be checked using an intravenous technique. Inject fluorescine in dose of 10 to 20 mg/kg. Tissue which does not flouresce is not viable and should be debrided. Matsumotog powders the wound with 5% methyl blue where devitalized tissue keeps the blue color which turns into the black later on. This change could last up to ten days. On the contrary, within the first 30 to 60 seconds viable tissue changes its color into the light blue.

Subcutaneous fat tissue is poorly vascularized and vulnerable to infection. Therefore it is necessary to make an abundant excision of the fat tissue up to 50 millimeters from the missile track to the extavazation zone. Due to a poor circulation it is necessary to perform gross incision of fascia which further results in decompression of the swollen muscle and also prevents spontaneous closure of the war wound. Fascia must be cut longitudinally with supplementary transverse incisions, if necessary. Use retractors to distance margins of the wound and then inspect tissues deep inside. Necrotic muscles mass, blood clot, foreign bodies, pieces of cloths are first to spot. With dressing forceps remove foreign bodies and clots. The necrotic muscle should undergo primary management, then incision, excision, bearing the **rule of 4C** in mind:

- **color;**
- **contractility;**
- **consistency and**
- **capacity to bleed**.

Parts of the muscle or muscle with no physiological color, with no contractility or muscle which does not bleed, should be re-cut. Attempts should be made to remove foreign body (shell fragments, bullet, etc..) but these attempts should not be tried at any cost. "Random digging" can cause more complications then presence of the foreign body, particularly if such foreign body does not jeopardize vital organs of the wounded. Availability of the mobile X-ray with monitor in the operating theater should facilitate removal of the foreign body under X-ray control.

Careful haemostasis is essential in the war wound management. Do your best to ligature all blood vessels in situ. Blood vessels should not be ligated with any other tissue, e.g., nerve, muscle.

If one of the main blood vessels is injured the following can be considered in management: lateral suture, lateral graft, direct anastomosis or graft anastomosis. End to end anastomosis is easier to perform, it requires less time and results are good. Subsequently, one can deliberately manage the limb abbreviation using external fixation for the stabilization of the bone fragments.

1.3. Primary surgical management of the bone tissue

There are some dilemmas with regard to the osseous tissue management.

In war wound bone fragments are loose. The amount of devitalized bone tissue found on bone fragments will depend on: vascular damage, damage to periosteum, endosteum and number of dead osteocytes found on the fractured bone. Destruction of the osseous tissue is proportional to the kinetic energy transferred to it. Devitalization of the osteocytes in the shaft extends to about 1 to 2 mm, in metaphysis 2 to 5 mm proximally and distally from the fracture site. Considering that there are no exact parameters and criteria for the intraoperative evaluation of the bone vitality, in the osseous tissue management it is difficult to evaluate vitality of fragments as such. Most common parameters are:

1. bleeding from the exposed bone fragments;
2. periostal damage of the bone fragments;
3. extent of the bone loss

Too radical approach leads to a great bone defect while approach not radical enough creates ground for osteomyelitis development. Fragments foxed by periost are lavaged "in situ". All fragments with stripped periost are properly cleansed, lavaged in physiological saline and placed back into the own site. [67,68,70,74]

Certain authors approve removal of the small fragments from the bone canal as well as those found far from the chief fragments. [8,14,69,70]

Damaged, (with no periost), detached fragments are prone to posttraumatic necrosis since neither medullar nor musculoperiosal blood supply is preserved. In my experience, such fragments, with no periost, should be removed regardless their size. Doing so, we establish the eventual size of the bone defect and surgical problem ahead. Placing back fragments with no periost, in majority of cases, problem is only uncertainly postponed and definitive management becomes more complicated.

In the primary war wound management, there are no indication for stabilization of bone fragments using AO-plates or an intermedullary nail. [10,19,41,44,70,74]

For stabilization of major bone fragments single screws may be used, with certain risk, as "mini-osteosynthesis". If external fixator has adequate technological features, "mini-osteosynthesis" may be avoided along with the accompanied risk.

If biological covering of the bone tissue is not feasible during the primary wound management, bone defect should be covered with gauze soaked in saline or Ringer lactate.

Attempts should be made to cover the bone with musculocutaneous flap within 5 to 7 days.

Gunshot fractures caused by low initial velocity projectiles are not complicated and do not require gross exploration of the missile track [69,70] Entry and exit wound edges are excised, missile track is irrigated. As early as three days, wound closure can be performed, if wound appears clean.

If projectile remained in the tissue, decision on removal is brought in the context of risk possible sustained with removal. It is necessary to remove projectile found in the joint since it leads to a chronic synovitis.

2. CLASSIFICATION OF OPEN FRACTURES IN WAR WOUNDS

During the Spanish Civil War, Trueta introduced principle of leaving gunshot wound open and attempted to establish war wound classification based on osseous tissue damage. McAndrew, in relation to prognosis and treatment, divided gunshot fractures to stabile and unstable.

Johner R i Wrush O. offered classification of the dyaphiseal tibial fracture considering the mechanism of the injury, comminution degree, fracture shape, etiology.

In eighties, several classification of the gunshot fractures were introduced, considering:

1. etiology;

2. extent of the musculo-cutaneous destruction;

3. pathoanathomical changes in bones;

4. localization on the bone;

5. anatomical destruction of structures vital to the limb.

According to etiology, we distinguish gunshot fractures caused by antipersonnel weapons projectiles and those caused by fragments of the explosive devices. [63,68]

The extent of the musculo-cutaneous destruction (skin, muscle, nerve, terminal arterial vessels, veins…) is crucial for survival and functional recovery of the limb. [68]

Based on pathological and anatomical changes, gunshot fractures are complete or incomplete. Complete gunshot fractures may be simple and comminutive.

In relation o the fragments sizes, comminutive are divided to satisfactory small fragments and large fragments.

According to localization on the long bone, fractures are metaphyseal, diaphyseal and intraarticular.

In relation to the degree of comminution, gunshot wounds are clasiffied into three basic groups:

1.without or with minor comminution;

2. with mid extent comminution;

3. with major comminution.

Each group is further divided according to the fracture shape and injury mechanism into three subgroups. Fractures in the group one are caused by indirect and fractures into two other groups by direct mechanism. In addition, each subgroup is classified according to bone site - upper, miss and lower third.

Classification of the comminution degree is conditioned by contact existing between two chief fragments, following anatomical reduction. Accordingly, the first group includes simple, spiral, oblique and transversal fractures, without or with small communition where fragments are in touch following reduction.

Second group covers all fractures with one or more butterfly fragments and where, following reduction, chief bone fragments achieve partial contact.

The third group includes gunshot fractures with huge comminutions - comminutive, segmental, crush fracture.

In such fractures, following the anatomical reduction, two main fragments do not obtain contact.

3. CLASSIFICATION OF OPEN FRACTURES IN PEACE-TIME WOUND

In order to establish treatment protocols and to compare results of various procedures, to grade open fractures is of crucial importance. In the peace-time trauma, the most accepted numerical classification of the soft tissues open wound is based on amount of avascular and devitalized tissue.

Currently, there are three leading classifications of the open fractures:

1. Gustilo and Anderson ; 1976
2. Muler nad co-workers; 1997 and
3. Tscherne - Oestern; 1982.

Numerical classification, introduced in 1976 by Gustilo and Anderson became adopted worldwide. In 1987 Caudle and Stern made some changes to this Classification, further dividing into three subgroups based on the damage of the main blood vessels.

European publications commonly use the AO Muller and al. Classification or Tscherne -Oestern; American publications prefer Gustilo-Andreson Classification.

Fracture type I according to:

1.- Gustilo-Anderson - small punctuate wound up to 1 cm or smaller; caused by minor trauma, bone fragment tip is coming out; outside damage caused by low velocity projectiles, with small kinetic energy, from a large distance and with minimal soft tissue damage.

2. Muller and al. - Skin breakage from the inside out with a bone fragment.

3. Tscherne-Oestern - Without or with minimal contusion, insignificant bacterial contamination; simple fracture or fracture of mid-severe degree.

Fracture type II according to:

1. - Gustilo-Anderson - Greater wound caused from outside with visible damage to the skin, subcutaneous tissue and muscle but associated with little avascular, devitalized tissue or presence of foreign material.

2. Muller and al.- Continuity of the skin is interrupted and contused from outside, followed with certain damage to skin, subcutaneous tissue and muscle. Size of the fracture varies.

3. Tscherne-Oestern - Damage to the skin and soft tissue is circumscribed; extensive contamination.

Fracture type III according to:

1. Gustilo-Anderson - Severe injuries with extensive skin breakage, damage to the subcutaneous tissue and muscles, associated with extensive necrosis, devitalized tissue and minor loss of bone periost along with presence of foreign body (material).

Type - 3A - Wounds with extensive damage to muscle mass, nerve or tendon injury; with flap tissue. Wound caused by high-energy trauma associated with extensive comminution; adequate soft tissue coverage of the fractured bone.

Type - 3B - Wounds with spacious skin and soft tissue defects, along with various degree of the bone loss and periostal stripping, high degree of the wound (fracture) exposure to external contamination.

Type - 3C - Extensive wounds, bone comminution, complicated with major blood vessels damage requiring urgent repair.

Gustilo and Anderson classified gunshot wounds in special category of third grade.

2. Muller and al. - It is usually result of the high energy injury, followed by extensive skin and subcutaneous damage, damage to muscle and neurovascular structures. It is often associated with injuries of blood vessels and nerves and often contaminated.

This grade extends to gunshot injuries caused by projectile with high initial velocity.

Revised Classification of Miller and al., dated in 1991, allows for further differentiation of injuries to the skin, muscles, tendons and neurovascular structures. It provides ground for the better grading of the soft tissue injuries. It also requires better understanding of the clinical practice.

3. Tscherne-Oestern - Extensive damage to the soft tissue, often associated with additional blood vessels injuries, nerve injuries and severe contamination.

Fractures type IV according to :

3. Tscherne - Oestern - total or subtotal amputations

3.1 The mangled extremity severity score

The use of classification systems for open fractures has been extended recently to cover lower extremity trauma that may require an amputation. The commonest of these scoring systems, the mangled extremity severity score (MESS) merits description.

The MESS is relatively simple rating scale for lower extremity trauma based on extent of soft-tissue injury, the extent of limb ischaemia, the degree of hypovolemic shock and the patient's age.

Johansen and his co-workers (1990) undertook a retrospective study of 25 consecutive patients with 26 severely injured lower extremities, all associated with acute arterial insufficiency necessitating re-vascularization. Seventeen of the limbs were salvaged and nine required amputation. A retrospective analysis using the MESS system showed that all 17 salvaged extremities had scores bellow 7, while 9 amputated extremities had scores ranging from 7 to 11. A subsequent prospective evaluation in 26 patients showed good correlation between the score and requirement for amputation.

It is not suggested that scoring systems such a MESS should replace expert assessment of severely injured extremity but such systems help to focus surgeon's attention on the important parameters and provide a protocol which facilitates assessment. Further research into MESS and other scoring systems is required.

Type	Definition	Points
A	Sceletal/soft tissue injury Low energy (stab; simple fracture; "civilian"; GCW	1
	Medium energy (open or multiple fractures; dislocation)	2
	High energy (close-range shotgun or "military" GSW; crush injury)	3
	Very high energy (above and gross contamination; soft tissue avulsion	4
B	Limb ischaemia Pulse reduced or absent but perfusion normal	1*
	Pulseless, paraesthesias, diminished capillary refill	2*
	Cool, paralyzed, insensate, numb	3*
C	Shock Systolic BP always > 90 mmHg	0
	Hypotensive transiently	1
	Persistent hypotension	2
D	Age (years)	
	< 30	0
	30 - 50	1
	> 50	2

** Score doubled for ischaemia > 6 hours*
Table 1.

Table 1. shows method of scoring in the MESS system If total score is 7 or more, it indicates possible need for amputation.

4. FACTORS INFLUENCING OSTEOGENESIS IN WAR WOUND AND PEACE-TIME WOUND

In fractures, several factors influence on duration required for bone healing or bone union. In open fractures, in peace time trauma, especially in war time trauma, factors which influence bone consolidation are:

1. Energy transferred within the site of trauma, which will then determine degree of the fracture;

2. Bone transplantation accelerates osteogenesis in early phases of consolidation. The effect of an early bone grafting is proved by Shishkovich and Felinger, 1988; in three different serials of tibial fractures (1979 - 1986), they proved that an early bone grafting results in accelerated bone healing or bone union. In our practice, even today, bone grafting is commonly performed as an additional procedure, in secondary, alternative external fixation, in cases of slow, delayed unions or nonunions;

3. Fracture localization: upper or lower limb; it is known that fracture of certain bones, on certain levels, heal more slowly then fractures in other places (proximal and distal part of tibia);

4. Type of the injured bone also determines the osteogenesis : tibia, femur, fibula. Femur has two nutrient arteries and better vascularization then tibia;

5. Weather the fracture line is: within diaphysis, , metaphysis or epiphysis; weather it is placed intraarticularly, or the fracture affects two bones; consolidation or healing of the cancellous bone is more rapid due to more developed vascular net and due to cellular richness;

6. The size of fragments dislocation influences the course of osteogenesis; greater fragments dislocation indicates to greater periosteal stripping, which further leads to the proportional damage to the vascular net;

7. An open fracture is primary contaminated; it creates the ground for infection and soft tissue loss; thus an early repair should be performed. Degree of fragments reduction and distraction, type of immobilization used for the given limb, then damage to the soft tissue limb cover are also important.

8. Hyperbaric oxygen may stimulate or impede osteogtenesis, it will depend on the pressure applied as well as of procedure duration;

9. X-rays kill cells and obliterate young blood vessels and buds within the fracture gap; decelerating osteogenesis;

10. Electromagnetic field stimulates osteogenesis;

11. The age of injured person is in indirect proportion to the process of osteogenesis; Glucocorticoides, malignant and infectious diseases, slow down or impede the process of osteogenesis.

4.1. Influence of compression and stability of bone fragments on osteogenesis

External fixation permits a considerable instability to bone fragments, weather by the primary application of too flexible apparatus or, or by weight bearing or by secondarily significant resorbtion on the bone - pins contact surface, which may lead to delayed union or nonunion.

Simple fractures managed with external fixation require high stability , since all motion takes place along one fracture gap. High instability leads to the high degree of shear in one fracture plane and consequently inhibits fracture healing. Multifragmentar, segmental fractures are less vulnerable to certain degree of instability, since movements happen between several fracture gaps. It happens quite often that bone fragments stabilized with an external fixator are under no compression , unless an additional tensioning screw is used. If fixator contains telescopic part on its frame, biocompression may be achieved, or transmission of body weight and muscles strength passes through the bone not through the frame of external fixatior.

In majority of cases, there is a gap between fragments ends. With minimal motion, possible as a result of such comparative flexible fixation, only shear of moderate levels occur, due to a gap width. This limited instability results in increased callus formation and in an acceptable degree of resorbtion on bone ends; further on, it results in reliable secondary healing of the fracture. Burny (1979) from Brussels proved that micromotion on the fracture site is of great importance for the optimal bone consolidation and introduces the concept of **elastic fixation**. Elastic stabilization is achieved by external fixation or by muscles contractions, as an physiological fixation.

Axial cyclic micromotion of 0,5 to 1mm promote fracture healing, while micromotion of more than 1 mm impedes fractured bone healing. To provide optimal condition for fracture healing, stability obtained by external fixation must have dynamic character : full stability ate the beginning, towards the gradual de-stabilization in the course of treatment. [72,78]

Controlled instability may also be achieved by graded weight bearing. Dolder, in 1991, reports on serial of 27 patients with open oblique and transversal tibial fracture. He allowed full weight bearing on the injured limb, upon the soft tissue recovery , and in average, it took 12 weeks for bone to consolidate [76]

In 1984., DeBastiani publishes his experiences with 288 patients with acute fractures. In the beginning, fractures were managed with rigid external fixation (Ortofix). After 21 days, in average, when periosteal callus was visible on radiography, he would loosen the screw which previously blocked axial micromovements (telescoping) and then would allow dynamic weight bearing. Period of fracture healing was 3,4 up to 6,5 months. [76] Lazo-Zbirowski and colleagues had similar experiences in 1986; and Kenwrightov and Goodshipov in 1989. All clinical and experimental data indicate that controlled or limited instability in external fixation exercises an useful effect to fracture healing time, if degree of shear on the fracture site is minor.

Dynamization should commence in early stages of fracture healing Godshipov proposes dynamisation after one week of external fixation, DeBastiani after three weeks, while Hente and colleagues propose dynamization after 7 to 9 weeks of external fixation.

Most authorities agree that dynamization should commences in early stages of fracture healing or in controlled phases, in order to avoid destruction of newly formed inter-fragmentary tissue. [34,45,57,59,68]

Functional weight bearing is a powerful stimulus for improvement of vascularization and nutrition of the entire limb, including fractured bone. Functional loading prevents osteoporosis and thus decreases time required for the establishment of the normal bone structure.

In my practice, in lower limbs fractures, I allowed painless weight bearing to the injured leg a day or two following surgery. Isometric exercises would also commence. Due to a pain, it is difficult determine if weight bearing, on the first postoperative day, was 5 % or 25 % of body weight but it did increase steadily. First dynamization I performed in fourth week following external fixation. If external fixator had no telescopic frame for dynamization, I would loosen the frame and allowed full weight bearing on the injured leg.

4.2. Degree of stability of bone fragments for healing

Biomechanical tests showed significant differences with regard to degree of stability achieved by various techniques or implants. Securing reduction by plaster immobilization, nearby joints must be immobilized, for increasing stability of the fractured bones. Low degree of shear between bone fragments induced callus formation and union, while high degree of shear induced callus formation as well but with no union.

Consolidation of fractures with rigidly stabilized fragments is characterized by minimal callus , and with no resorbtion on fragments ends. Healing without obvious callus requires implant protection , for later period of bone remodeling. Primary fracture healing is less stabile then consolidation by secondary callus formation. Risk of re-fracture is greater.

Such type of healing may be following external fixation, but it is not seen as an objective.

Controlled or limited instability may result in increase of callus production. Such bone consolidation is followed by acceptable degree of resorbtion on fragments ends.

Minimal internal osteosynthesis with tensioning screws between main diaphyseal fragments and production of interfragmentary compression, in combination with external fixation, may be surgical challenge but gives no advantage. If screw is used, anatomical reduction is accomplished, firmness is increased and bone usually heals with primary callus. Serious disadvantage is high degree of re-fractures and soft tissue complications. In 1984, Burny and colleagues state tat if screw is used, consolidation may last even longer then if external fixation is used , while degree of pseudoarthroses does differ in both cases . (12,16) Krett et. Al, in 1989 report on re-fracture of bellow knee, following treatment with tensioning screw and eternal fixation, in 10,9 % of cases and in stabilization with external fixation only in 4,5 % of cases.

Controlled instability, regardless controlled weight bearing or progressive frame dismantling (sliding, telescopic, or De Bastiani 1984; Lazo-Zbikowski 1986; Hente 1988) leads to increased callus formation. Kewright and Good ship emphasize controlled axial micromotion on the fracture site and in 1989 use small pneumatic regulators for controlled limited instability.

In the post, external fixator was left on site until bone consolidation appears, 9 to 10 months (Gershuni, Halma, 1983; Schroder, 1986). Recent reported serial indicates that 4 to 5 are needed for bone to consolidate, when external fixation may be removed (Thurk, 1988, Hax, 1989; Heim, 1990). They agree about two basic factors affecting bone healing in open fractures:

1. condition of the soft tissues following trauma; or vascularity of the fracture site;

2. control of mechanical shear forces and commencement of weight bearing in external fixation; or dynamization (change of axial forces across the fracture site, without no fragment dislocation).

Non-controlled or large instability may delay or prevent bone union. Inadequately placed external fixation , which allows extensive instability of bone fragments, weather due to primary application of extremely unstable apparatus or due to secondary excessive resorbtion on pins-bone contact surface, are most common causes for delayed union or pseudoarthrossis.

4.3. Fracture healing with regard to the fracture type and method of stabilization

Reparation cycle start in the moment of trauma, lasts for 3 - 4 weeks, then ceases and does not repeat. Within this period , it is necessary to provide full reduction of fragments and their absolute fixation. Further on, in the period of accelerated bone remodeling, it is necessary to weaken degree of fixation, gradually. This is achieved by gradual pins removal, one pin in 4 to 5 days. The change in fixation firmness may influence on reparation process. Treatment of the broken bone, with or without defect, by reduction and preservation of reduced fragment , aims at full bone consolidation. Stabilization of reduced fragment may be maintained by traction, plaster of Paris immobilization, internal fixation (AO plates, intermedullar pins,…) and by external fixation. In all cases, biomechanical analysis indicates significant differences in degree of stability achieved with different techniques, respectively.

If reduction is maintained by plaster of Paris immobilization, nearby joints are immobile in order to achieve stability of the fracture. The aim of internal fixation is to stabilize internal fragments and to allow an early mobilization of nearby joints and thus minimizes the atrophy.

In stabilization with AO plate, the aim is to achieve absolute stability. Stability of bone fragments is achieved through inter-fragmentary compression, which fully prevents movements between bone fragments.

It may only appear that achieved stability prevent fragments micromotion. Cellular elements of reparation are invisible for the eye. Fractured fragments managed by pin or AO plate may not show visible movements under loading. Invisible degree of loading may damage a bone cell if the motion is of the same size as the cell.

The term which helps to understand this relation is called shear and it understands deformation of cells or relation between original distance of fractured fragment, divided according to degree of motion. [33,43,46,48,67,68] Perren and Cordey (1980) applied shear according to tolerance of differentiation of tissue repair and report that tissue differentiation is controlled by domineering mechanical conditions. Simply, potential shear equals to gap width divided by perpendicular movement on the fracture surface. ([2,35,42])

Using the model of cones osteotomy (1991) , Hente with colleagues investigated the influence of dynamic shear as a gradient from 0% and 100 %. Small values of shear , between 0 % and 20 %, resulted in callus induction and union, while higher degree of shear induced callus formation but with no bone consolidation (pseudoarthrosis). [37] Hente and al. recognized the importance of repeated shears during the day. High degree of repeated shears (10 000 cycles a day) induced minor callus formation; while significant callus production occurred following 10 daily applied cycles of fractured stiffness.

More and more authors agree that minor shear degrees (up to 33% or 0,5 mm) are useful for the bone fracture healing. High degree of shear inhibits the process of healing. [33, 36, 39,43,47, 49,51,53,55,59]

Fractures stabilized so rigidly show direct consolidation, characterized by minimal callus production , with no resorbtion on fragments ends and, direct bone formation. With rigid stabilization, attempts are made to avoid inter-fragmentary motion within limited stress, present after an early functional treatment, in order to prevent resorption on fragments ends and on the implant and bone contact surfaces. Healing "without callus" still requires protection of implant for the later period of bone remodeling. Fracture healed by primary bone healing is less resilient and stabile to micro trauma then fracture which is consolidated by secondary haling along with production of voluminous callus. (Fig. 9)

Fig. 9.

When AO plates and intermedullar pins are used without inter-fragmentary compression, there is a minimal resorbtion on contact surfaces and, in majority f cases, there is crack between fragments. With minimal motion, achieved as result of comparative tolerance, a moderate shear appears between bone fragments. Due to substantial gap width, developed by resorbtion on contact surfaces, (with regard to cells size) , an influence of induced micromotion between bone fragments is made possible. In fractures exposed to axial irregular mechanical stimulus during a day (17 minutes), shear as 33 % and utilization of these micromovements commenced seventh day following osteotomy. [2,4,56,67]

External callus appeared earlier, a torsional stiffness after 8 to 10 weeks was significantly bigger in comparison to rigid (AO) stabilization. Same authors in 1989 recognize that 3 mm gap in diaphyseal osteotomy , with motion of 0,5 mm , leads to the increase of fractured stiffness and bone mineralization in the gap, in comparison to rigid stabilization. Movements of this 3 mm gap for more than 2 mm and more is harmful for both mineralization and resorbtion extent, resulting in secondary instability, which is not tolerated and questions the final consolidation [4,4,56]

Controlled or limited instability of bone fragments may lead to increase in callus production, with acceptable degree of resorbtion on fragments ends, leading to the secondary callus formation. This type of healing results in prompt and reliable bone consolidation. Instability control is achieved by controlled weight bearing or by progressive dynamization of external fixation.

Uncontrolled or too extensive instability may delay or impair solid bone healing.

Stability or instability will depend on frame firmness of external fixator, on mechanical quality of pins, on pin holders, on distance to the bone… Fractures with large diaphyseal surface (oblique, spiral) show better results in managed by external fixation, then short, oblique or transversal fractures with small contact surface.

Condition of the soft tissue following trauma and bone fracture is of great importance for the process of healing. In open fractures, blood supply is impaired by trauma itself, and thus an open fracture takes longer to heal, under the same mechanical conditions. Krettek and al. (1989) investigated on serial of 202 acute fractures and concluded that tibial fractures, with soft tissues injuries (open fractures) take, in average 18,4 weeks; while tibial fractures preserved cover of the soft tissue (closed fractures) take 15,4 weeks. This confirms the importance of comprehensive soft tissue coverage for the bone healing, not only the importance of periosteum, as some indicate.(3,6,17,23)

4.4. Importance of bone vascularization for bone healing following internal and external fixation

Trauma (war- or peace trauma) which results in interruption in bone continuity, will also damage blood vessels as well as surrounding soft tissue. Primary war trauma usually damages complete vascular net of the bone, while peace time trauma, depending on force, may damage vascular bone net completely or incompletely. Intramedullar circulation, then periosteal and vascular net in metaphysis and epiphysis may also be damaged.

In peace-time trauma, in transversal and spiral fractures, where dislocation is less than transversal diameter of the fragments, nutrient artery is most commonly intact. In comminution fractures nd in fractures with dislocation larger than transversal diameter of the fragments, nutrient artery is damaged. In such cases, priosteal vascularization and vascularization in metaphysis and epiphysis, then expansion of blood vessels lumen and formation of many anastomoses, will all function as a compensatory mechanism.

Bone tissue trauma and vascular net damage lead to bone necrosis. The extent of bone necrosis within the fracture zone is directly proportional to degree of vascular damage. Apart from the interruption of bone continuity in war wound, which is primarily contaminated, e find foreign bodies, maceration of muscles, damage to neurovascular structures. In peace trauma also, on the fracture site, there will be cavity filled with extravazation, with bone fragments and pieces of soft tissue floating. In comminution fractures, free fragments are usually with no blood supply at all. As detachment of soft tissue from bone fragments is greater, so is fracture instability. Unstable bone fragments lead to additional damage to osseous, musculo-cutaneous tissue and blood vessels.

Fracture stabilization is very important for bone fragments re-vascularization and fracture consolidation. To perform stabilization of fractured fragments with an AO plate, intramedullar pin , it is necessary to detach soft tissue and to perform additional periosteal stripping, what is conscious iatrogenic damage to vascularization in the zone above and bellow the fracture. Cortex site, where plate with screws is placed , has reduced vascular supply. By placing AO plate, following periostal stripping, as Schauwecker (1987) states, cortex undergoes necrosis, involving half of the cortex thickens.

When reaming intramedullar canal in order to achieve adequate stabilization with an intramedullar pin, vascularization of internal two thirds of cortex is compromised, along the entire bone. An additional damage to periosteal vascularization in the heart of fracture occurs when intramedullar pin is placed by an open method. Closing anastomosis between intermedullar and periosteal blood supply system is contra productive.

Such mass vascular damage impede the process of fracture consolidation and increases probability for post-operative osseous infection; due to a local hypoxia.

External fixation and stabilization of bone fragments with pin or wires passing through parts of skeleton and externally fixated for a frame, allow for maximal preservation of bone vascular net, both periosteal and intramedullar. It further provides ideal biological conditions for fractured bone healing , while infection rate is reduced to minimum.

4.5. Primary healing of soft tissue

Non-infected wound heals best and most rapidly !

The wound which undernt primary surgical treatment will heal as "reparation per primam intentionem". Surgical wound management causes death to only limited number of cells of the skin, connective tissue… Free space in the wound is minimal and soon filled in with exudate and blood. Blood clot on the wound surface causes an inflammatory reaction, where mainly neutrophiles are attracted to. (56) Epidermis thickens by mitotic divisions of the basal cells, and spikes of epithelial cells reach along the wound, into a depth, producing epithelial wound layer. Epithelial reaction is rapid and develops prior to the reaction of the connective tissue bellow. Histologicaly, from the third day on, there are significant changes in the wound, with appearance of a monocytes. Collagen fibrils are present as well, bridging the cut.

Monocytes clean the wound from the necrotic tissues, leukocytes and fibrine. Wound healing is achieved by mitotic division of fibroblasts and endothelial cells, with speed of 0,2 mm per day, according to Cliff.

On the fifth day, cut is filled with porous vascularized, fibroblastic connective tissue. Capillary buds from both sides of the wound unite into continuous channels, increasing the vascularization. Increased number of collagen fibrils allows epidermis to reach the original thickness.

During the second week, collagen fibrils and fibroblasts multiply, under the epidermis with normal thickness now. Increased mass of fibroblasts and collagen presses on the newly formed capillaries, which become thinner and transform into definitive capillaries in the wound scar. By end of the first month, scar is still composed of overly vascularized connective tissue, with predominantly intact epidermis .

It can take even a year for collagenous scar to form. Hair follicles, sweating and sebaceous glands, previously destroyed, will never recover. Yet, those partially destroyed, along the lateral cut, may recover.

4.6. Secondary healing of soft tissue

If extensive soft tissue defect are present, requiring compensation, the process of reparation is much slower. Hystological and physiological process of the soft tissue does not differ from the primary healing. Large tissue defects contain more necrotic detritus and exudate, which must be removed. Inflammatory reaction is more intense, as well as migration of monocytes, leukocytes, and fibrine. Inflammatory reaction ceases only upon complete detritus removal. Macrophages do the wound "cleaning", via proteolitic ferments and drainage towards outside. Presence of exudate in tissue defect prevents healing.

The main difference is in the quantity of produced vascularized tissue, known in daily practice - "granulation tissue". It is an grate protective cover for every wound and salvages all important tissues, such as: nerves, blood vessels, bone, cartilage from the drying out. Granulation tissues growths from the bottom and edges of the wound upwards, producing scar. Based on clinical features, very often two terms are used: healthy granulation and unhealthy granulation tissue.

Healthy granulation tissue is thin, solid, light-red membrane with refine granulation surface, does not bleed easily and has no odor. There is a secretion on the surface, more alike transudate than exudate. Wound edge has epithelial border and there are no clinical signs of infection.

Unhealthy granulation tissue is pale and cyanotic, wet and soft due to edema. Minor bleeding is present on the surface, which is rough and uneven due to extensive growth. Excessive exudation and pus cover the wound. Clinically, patient has intoxication signs: raised temperature, local edema and lymphadenopathy.

Granulation tissue starts to mature on the peripheral wound areas. In time, it reaches status of formed cicatrix, covered or not covered with epithelium. Contraction of the scar tissue plays an important role in the process of healing for large wounds; namely contraction of scar tissue decreases the surface requiring the epithelization.

Scar tissue is not resilient to tensile forces, but can stretch to some extent. With increase of tensile force , a complete disruption may occur.

Properly sutured wound, in layers as well as regular stitches density, present some of the most important factors for wound firmness.

5. RADIOLOGICAL ASSESSMENT OF BONE CALLUS

Radiological examination is available and important method in assessment of bone consolidation. It is based on visual evaluation of callus formation and mineralization, within the area of fracture.

Dynamic process of production, mineralization and development of callus is followed by control radiological examinations and by clinical check-ups. Such evaluation demands a great experience in radiological diagnostics. Weather callus occurred, how much of it is present, how is it distributed, is it more callus on current radiography then on the previous one, a month ago, how solid it is, could immobilization be removed, how much to load the injured leg and still to prevent re-fracture, did callus start to remodel, etc.. all these questions ask for an answer in daily practice. Conclusions and decisions are made on basis of radiographic shots , which are looked at with naked eye, some under the magnifying glass.

For the adequate radiological evaluation of the callus production, radiography of the broken bone is done in antero-posterior and latero-lateral projection. Half-oblique shots are made in order to gain better insight into callus formation. Such shots visualize the entire bone circumference, so more information about spacial position of the callus . Tomography offers additional data on osseous consolidation. Long bones are usually treated with linear tomography of 0,5 cm, while also half-circular or polytom may be used. Some cases of fracture (scaphoid bone) are followed on by macro-radiography, providing better visualization of details within the fracture site.

According to radiographic signs, there are two types of osseous consolidation:

Fig. 10.

- direct, primary osseous consolidation and
- indirect, secondary osseous consolidation .

5.1. Primary osseous consolidation

Each fracture heals in its own way!

Consolidation will depend on : age, gender and general health status of the injured, on type, localization and shape of the fracture (open or closed fracture), on biological potential of tissues, on therapeutic approach… In order to treat the fracture, one needs to be familiar with the process of fracture healing.

Primary osseous consolidation is , as rule, ensured by stabile osteosynthesis of fractured fragments, which are perfectly reduced, neutralized and fixated in a stabile block. Augmented inter-fragmentary pressure prohibits any micromotion on the fracture site. Absolute rest and uniformly divided pressure on the fracture site create ideal static and dynamic conditions for osseous consolidation. Fractures managed as described heal endostally and on radiography, periosteal callus shall not be noticed in either of treatment phase. (Fig. 10)

With well performed inter-fragmentary osteosyntesis, on postoperative radiography fracture is not visible or it is visible a s line, on some parts hardly noticeable. When fracture line is not visible on postoperative radiography, follow up and decision making on osseous consolidation may be approximate and uncertain. Callus evaluation under such conditions demands experience and knowledge of radiographic signs of bone healing.

Fracture line gradually narrows and shortens, and in subsequent comparison of control radiography, it becomes smaller,, narrower, unclear and eventually, not visible on radiography.

Bone condensation on fracture site is minimal, it differs in fracture site density in subsequent radiographs, and eventually this density difference is hardly visible . At the beginning of endosteal callus, within the fracture site, few rare, somewhat thicker osseous columns are visible as well as minimal density difference. With time, the number of osseous columns of normal thickness increases. They place along the bone axis, parallel among themselves, following the structure of normal bone. When healed, fracture site is re-structured and bone trabecules of that area, in quality and quantity , respond to normal bone structure.

If , during the course of treatment, callus is noticed on radiography, there are disturbances in primary osseous consolidation: Developed callus , as difference to normal periostal callus, is called as irritate or simulative callus and its properties are:

- as callus , it is less valuable, does not fix bone fragments;
- it has unclear borders;
- it is not structured;
- results from movements of fractured fragments.

Transparent areas seen on radiography around osteosynthetic material (AO-plate, screw, pin), correspond to defects in osseous (cortical or cancellous) substance. Such sites develops due to a intermittent forces of torsion, pressure, shear or due to infection (ostitis - osteomyelitis) which further lead to erosion of the osseous substance around the osteosynthetic material. The consequence is disturbance of osseous consolidation by primary, endosteal callus, as result of instability among bone fragments. Instability may occur is osteosynthesis surgery is not properly performed or if , following an adequate osteosynthesis, premature and too excessive weight bearing starts.

It the following triad of signs persist on control radiography:

- interfragmentar line expands;
- periosteal callus is formed;
- lysis around osteosynthetis material

then these indicate to disturbed primary bone healing and presence of instability among fractured fragments.

Declining the cause of instability , irritate callus transforms into fixational, which is clearly recognizable for its osseous structure. Fracture gap gradually decreases, becomes more dense and re-structures into osseous tissue.

5.2. Secondary osseous consolidation

Secondary or indirect bone consolidation is defined as consolidation of such bone fracture where, on successive radiographs of the fracture, periostal callus is visible and followed on during several months. The very same callus takes years to remodel into normal lamellar bone. Secondary fracture consolidation occurs in all cases of fragments motion.

Callus develops from periosteum, endostat and from the content of Haverisan channels. Granulation tissue develops firs, then osteoid; then crystal apatytes are laid into osteoid.

In first 15 days following fracture no callus is visible; granulation tissue and osteoid of the callus are not visible on radiography. Within this period processes or osteolysis may be visible on radiography, seen as decalination of edges of bone fragments, lighter than the nearby bone and a bone atrophy on the fracture site. For these reasons fracture gap is better and more clearly visible then it is the case immediately after fracture. F bone defects are distanced or if there is bone defect, decalcination of fragment edges may be missing. Mentioned decalicination, then atrophy of bone ends, are an early sign of physiological consolidation of fracture but means no absolute guarantee for normal bone healing process.

First signs of periostal callus formation are visible on radiography 2 to 3 weeks following fracture ; it will also depend on patient's age, fracture site; (which bone and type of fracture). In bones with tiny musculature, little periosteal callus is formed; where muscles around bone are voluminous, periosteal callus will be more extensive as well. Periosteum of skull does not heal with periosteal callus, due to lack of osteogenic properties, so does intra -capsular region of femoral neck, which has no real periousteum.

First a gentle, cloudy shadow is visible on one place, then on more places, along the bone, on small distance from the fracture site, then on more places in soft tissues. (Fig.11) Shadows become confluent , more dense, spread around the fracture line, embracing the fracture. With minerals depositions, callus is more and more visible on radiography, becomes more dense and develops into solid, bridging callus between bone fragments. (Fig. 9) Callus borders are not sharp, it is non-homogenous, of irregular density , with no structure. Fracture gap is hardly visible and slowly disappears.

Bon consolidation is completed when a continuous mineralized zone between distal and proximal fractured fragment is visible on radiography.

In coming months periosteal callus becomes more dense, more clearly distinctive, starts to restructure and to remodel.

Fig. 11.

Endosteal callus develops and calcifies along with periosteal callus. On standard radiography is hardly noticeable since it is covered by external bone parts and more distinctive newly formed periosteal callus. After 1 to 2 weeks it is more noticeable on radiography, when de-calcification and bone atrophy of fractured fragments occur.

Visible endosteal callus is seen in vertebral fractures, as ell as in fractures of pure cancellous bone, as in fractures close to the joints.

In the beginning of consolidation with endosteal callus, an irregular zone of osseous density is visible, this zone enhances with time. In ednosteal fracture healing, inner borders of fracture gap become blunt, unclear, and finally, disapear,; it also depends on callus mineraalization progress. Homogenous shadow of ednosteal callu iss gradually replaaced by cancellous bone.

The latest stage of endosteal callus consolidation is re-structuring of an endosteal callus into compact - cortical bone and cancellous bone structuring.

According to both, clinical nd radiographic signs, fracture is consolidated, fracture site is overgrown with newly formed osseous trabecules and overly structured cancellous bone is present. Trabecules, cancellous bone lines, then cortex structure in the fracture site are identical to surrounding bone.

IV - STABILISATION OF BONE FRAGMENTS IN WAR - AND PEACE-TIME TRAUMA

Gunshot wounds of the limbs have to be stabilized. In open fracture, in both peace time wound and war wound commonly used techniques: plaster of Paris immobilization, and transosseal traction give space to external fixation.

Clinic for Orthopedic Surgery and Traumatology , in the period from 15th September 1991 until 1st December 1995 offered primary surgical treatment to 2462 wounded with limb injuries. Average age of wounded was 33,73 years. Apart from limb injuries, 157 (5,57%) of wounded has sustained multiple injuries: abdominal injuries were present in 98 (3,98%); thoracic injuries in 25 (1,01%); craniocerebral injuries in 34 (1,38%) wounded. Chief blood vessels were affected in 182 (7,39%) wounded; neurological injuries of the peripheral nerves were present in 45 (1,82%) wounded.

In 2197 (89,23%) there was necessity for bone fragments stabilization. External fixation was performed in 1573 (72%); traction in 91 (4%) and plaster of Paris immobilization in 531 (24%) of wounded.

Fourteen types of external fixators were employed - external fixator Mitkovich M 20 was employed in 1342 (85%) of wounded; whilst other 13 types of external fixators were used in 231 (15%) cases.

Concept of bone fragments stabilization by external fixation (Fig. 12) proved to be most efficient for the open fractures (Gustilo II and III) and for the war wound of the limbs (types of the war wound II and III grade). The rationale :

1) Fast application of the external fixation;

2) Minimal blood loss;

3) Patient is soon mobile, independent in the ADL; low demand for the staff care ;

4) Primary external fixation enables perfect control of bone fragments; both intra-operatively as well as post-operatively fragment reduction.

5) The bone is freed form the foreign bodies; blood supply is preserved - both periosteumal and intramedullar vascularization;

6) Dynamization of the external fixation allows adjustment to ideal biomechanical conditions in the course of treatment;

7) Lowered risk of ostitis and osteomyelistis;

8) Wound is daily accessible; better care is possible;

9) Cost efficiency; shortened treatment duration; better final outcomes.

My experience, based on years of former Yugoslavia war, and results we achieved allow me to consider external fixation as an absolute indication for the bone fragments stabilization. Following primary surgical treatment, external fixation should be performed in all fracture wounds caused by firearm.

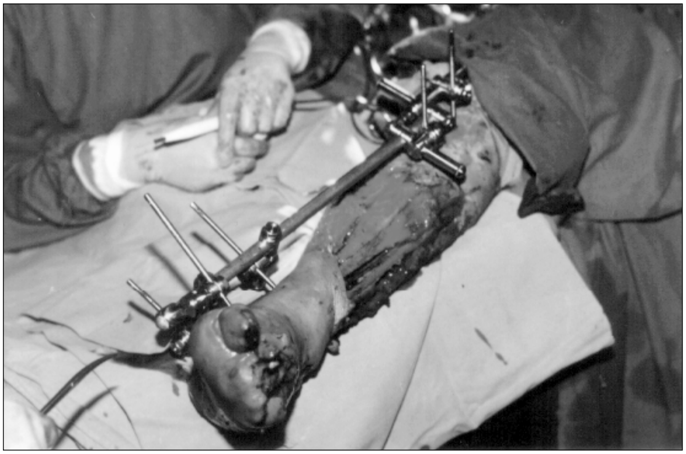


Fig. 12.

1. TRACTION / EXTENSION

After an adequate primary treatment of the wound, soft tissues also, it is necessary to stabilize bone defects. The easiest stabilization method includes skeletal traction, which provides reduction as well as fragments partial immobilization. This treatment can be either temporary or definitive. Traction will maintain adequate position of the fragments for initial, occasionally until eventual bone healing. Traction can be direct (osseal) or indirect (cutaneous). Most commonly used traction are: Baumano'vertical bone traction for humerus, supracondylar femoral extension for the proximal femoral fractures; traction through tibial tuberosity is indicated for fractures of distal femur. Skeletal traction through calcaneus is indicated in the lower limb injuries. Regardless the fact that traction is a simple method where callus is rapidly formed, in the treatment of gunshot wound fixators are gradually replacing the traction. Shortcomings of traction techniques are: inaccessible wound, long bed rest, increased risk of ischaemic ulcers, poor personal hygiene, pneumonia, calculosis, tromboembolias, extra workload for medical staff.

2. PLASTER OF PARIS IMMOBILIZATION / CASTING

Compared to external fixation, plaster of Paris, as an immobilization method, following primary wound treatment is less and less used. Reasons lie in difficult reduction and retention of bone fragments; in poor access to the wound and subsequent difficulties with wound toilette, prevention of mobilization of the unaffected joints and increased consumption of the surgical material and demands for surgical team (Fig.13)

Fig. 13.

With more and more experience in this war, I started to favor stabilization with external fixators. During the period of 15.06. until 01.12. 1995, the period of extensive military operations, out of 311 injured, external fixation was used in 286 cases (92%); extension was used in 3 cases (1%) while plaster immobilization was used in 22 cases (7%).

Functional cast immobilization is widely used in treatment of injured limbs, as placed after removal of an external fixator. External fixation is applied as an extra support to the healing fracture - in order to prevent limb re-fracture or angulation. Most often used rational plasters are: Coldwell's hanging cast; Monney - above knee functional plaster of Paris; Delbte plaster, Sarmiento below knee functional plaster.

Following dismantling of external fixator , functional cast was employed in 90 % of cases.

Cast with incorporated Stainman pins, with window above the was wound, carries a risk of complications: cast is soaked with blood and antiseptic solution; wet cast in unstable; clean wound and stabilization of the bone fragments can not be obtained.

3. EXTERNAL FIXATION

The external fixator is device used in orthopedic surgery, war- and peace-time trauma for the fixation of bone fragments, with pins inserted through the skeleton and fixed outside for the external fixator mounting. This treatment technique is called external fixation. External fixation ensures stabilization and fixation of injured bone in desirable position. Further on, using an external fixation, in bone fragments, we obtain : neutralization, compression, dynamization, distraction, angulation, rotation, osteotaxis, ligamentotaxis and elastic fixations.

According to the biomechanical, technical properties, geometrical configuration and application mode for external fixation frame, there are: unilatral, bilateral, V-shaped frame, circular, triangular, semicircular, quadrilateral and unilateral with convergent pins types of external fixators.

3.1. Indications for external fixation

Indications for external fixation are specific. Each problem should be assessed individually; surgeon has to be familiar with all other conventional methods in order to decide upon the treatment of choice.

External fixation is primarily used for stabilization of open fractures sustained in peace time (Gustilo II and II) and gunshot wounds in primary surgery. However, it is a method for definitive stabilization in war wound management. The advantage in comparison to other methods is best seen in gunshot wounds associated with extensive soft tissue and bone damage. Popovic and al. [67] report that, in the last war, external fixation in primary surgery phase was employed in 54,5 % of gunshot wounds of different localization. As a method of definitive treatment, external fixation was used in 46,1 % of cases. Humerus was the site of the most frequent application (66,7 %); less often used for the foot gunshot wounds (10,4%).

Employment of external fixation in primary surgical management at Orthopedic Surgery Hospital Banjaluka during the last was as follows: lower leg 589 (84,75%); upper leg 509 (6,27%); upper arm 297 (76,55%); lower arm 159 (62, 35 %); hand and wrist (14 (9,93 %) and foot 5 (3,97 %). See Table 2.

Widely accepted, absolute indication for external fixation are as follows:

1. treatment of bone fragments in war wound caused by firearm, grade I and II;
2. fractures II and II according to Gustilo;
3. fractures requiring later cutaneous repair surgery;
4. fractures requiring distraction and neutralization of bone fragments, associated with a significant bone loss;
5. fractures of the long bones of the limbs, where the same bone length is important (radius, ulna) ;
6. fractures associated with burns and extensive skin loss;
7. infected fractures or nonunion and
8. arthrodesis.

Relative indications for the external fixation are as follows:

1. the war wound Grade I if F=1;
2. fractures of the pelvis with dislocation;
3. fragment fixation following radial resection of the tumor, with auto- or allo-graft;
4. osteotomy in children, namely external fixation eliminates the need for subsequent removal of osteosynthetic implants;
5. fractures requiring repair or reconstruction of the blood vessels or nerves;
6. stabilization of the segments in closed fractures;

Injured limb	number of wounded	primary stabilization done with external fixation		primary stabilization done with Kuntcher, extension, POP	
		number	percentage	number	percentage
upper leg	590	509	86,27 %	81	13,73 %
lower leg	695	589	84,75 %	106	15,25 %
foot	126	5	3,97 %	112	96,03 %
upper arm	388	297	76,55 %	91	23,45 %
lower arm	255	159	62,35 %	96	37,65 %
hand	141	14	9,93 %	127	90,07 %
TOTAL	2159	1573	71,66 %	622	23,34 %

Table 2.

7. correction of the congenital deformities;

8. enforced stabilization of the bone fragments;, particularly those where screws or wires are already placed but no adequate stabilization is obtained.;

9. ligamentotaxis , in intra-articular comminuted fractures, when by dragging the ligaments and capsular structures, reposition and stabilization of the fragments are achieved; this concept is convenient for distal radial fractures where currently plaster is used.

10. stabilization of fractures in polytraumatized patients who often require transportation for repeated diagnostics;

11. distal third lower leg fractures, if plaster immobilization proves unsatisfactory and

12. transpedicular stabilization of the spine in the war wound.

External fixation in gunshot fractures provides an adequate access to the injured tissue allowing care, follow-up and re-excision of the war wound. (Fig.14). Further on, there is an easy access for the primary delayed suture or secondary suture or wound covering using plastic surgery methods.

All procedures are performed with external fixation in site, maintaining bone fragments stability and limb length. External fixation does not require long application period, is mounted easily and it is user friendly. Damage to the soft tissues is less; rehabilitation is more complete, more rapid.

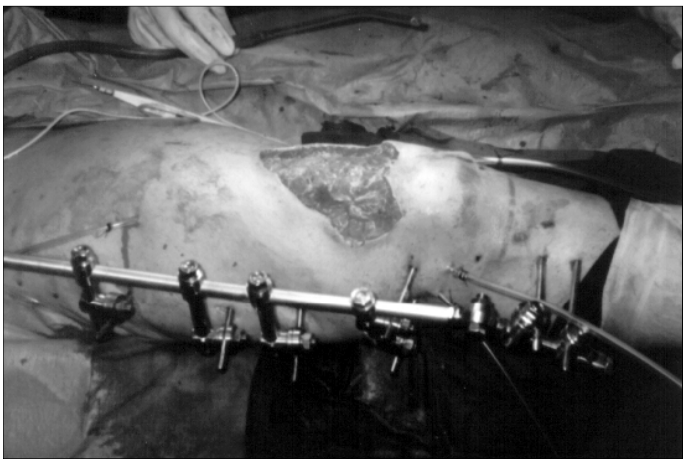


Fig. 14.

Shortcomings of external fixation are iatrogenic lesions to blood vessels and nerves, day care of the pin area - wire area, high frequency of the soft tissues infection around pins, even up to 80 %, (70,83,93) and osteomyelitis around pins can occur in 11 %; delayed union in 6 - 8 % (69,70,72) Inadequate pin - wire application lead to joint contractures.

Out of 1573 external fixations employed after primary surgical wound management at Orthopedic Surgery in Banjaluka, following complications were present: pin infections 172 (10,92%), pin breakage 3 (0,19 %); fixation re-mounting 42 (2,66 %); vascular iatrogenic lesions sustained by drill or pin 6 (0,38 %); neurological 4 (0,25 %). There were infections of the musculocutaneous tissue, signs of acute osteomyelitis, were excision were done (re-interventions) in 204 wounded among 2462 wounded who underwent primary surgical wound management. Despite surgical treatment and medicaments , there is chronic osteomyelitis in 72 (2,92 %) of wounded; sites are distributed as follows: humerus 7, radius 4, ulna 5, femur 21, tibia 31, calcaneus 3, matetarsal bone 1 (Dr Jakovljevic, 1998).

Bacteriological analysis revealed the following germs: Staphylococcus aureus 51,38 %, Pseudomonas spp. 13,82 %, Pseudomonas aeruginosa 12,50 %, Enterobacter 5,50 %, others 8 %, mixed infections 8 %.

Five wounded developed gaseous gangrene.

Following primary surgical treatment, certain number of wounded continue with treatment in Yugoslavia, Federation or third countries and thus data on subsequent treatment course are not available to us. If these data would be available to us, they wound probably have no significant influence on the final outcomes, but probably would slightly modify these outcomes.

3.2. Biomechanics of the external fixation

Biomechanics of the locomotor system in orthopedic surgery and traumatology studies physical properties of bones, muscles, cartilage, fascias, tendons and joint in both physiological and pathological conditions. Commonly used term in biomechanical research is rigidity and stiffiness of the apparatus for fixed bone fragments.

Biomechanical stiffness understand resilience of the fixed bone to the effect of three various forces:

1. axial forces: compression and distraction
2. bending forces: anterio-posterior bending and latero-medial bending;
3. torsion forces.

Biomechanical rigidity understands resistance of the fixation material on stability of the bone fragments.

In attempts to keep these forces within permitted limits, we use osteosynthetic material. For satisfactory AO osteosynthesis two principles are considered:

1. Principle of the interfragmentary compression - static and dynamic;

a) Static interfragmentary compression is achieved with prestressed AO dynamic plates and tighten screws.

b) Dynamic compression uses certain forces of the implant distraction, fractured bone uses compression forces occurring during normal use of the limb on the fracture site, e.g.; Zuggurtung in transversal patelar fracture

2. Principe of stabilization with intermadullary nail (schienung) in moajority of cases leads to no absolute stabilization of the fragments. Commonly, there is a secondary healing in diaphyseal area. Adequate medullar pin and medullar reaming increases stability.

In external fixation, biomechanical stiffness is obtained by the outside frame structure. Anterio-posterior instability is biggest when mounting, in unilateral and bilateral pin mounting; while latero-lateral stability is beyond optimal. Stiffness is significant in in big triangular and semicircular external fixators. [35,39,48,57]

External fixation rigidity depends not only on mounting technique then also on:

1. fracture type; (rigidity is bigger in transversal, well reduced fractures, then in comminutive, non-reduced fractures);
2. number of pins;
3. contact between the bone and the pin;
4. distance between the bone and the frame
5. pins grouping mode and the application site ….

V - LATE COMPLICATIONS OF OPEN FRACTURES

Treatment of patients with bone fractures presents a complex problem with uncertain outcome and treatment length. As every wounded is an unique person, so every bone fracture carries specific and unique properties .Healing depends on general condition of the wounded, on shape, type and localization of the fracture, on age and gender, on biological tissue potential… Complication following long bone fractures are particularly complex. Long bone fractures are characterized with extended zone of the soft tissue trauma, with impaired microcirculation and diminished vitality of the soft and osseous tissue. Treatment method is crucial for the eventual outcome, exercising influence on morbidity, mortality and permanent disability.

Errors happen along the line of first aid to the clinical treatment. Surgeon has to maintain active attitude. Most important complication of the open fractures are:

1. delayed healing and pseudoarthoses
2. osteomyelitis
3. malunion
4. joint contractures

1. DELAYED UNION - PROLONGED HEALING

Delayed union is a state in the healing of fracture in which the fracture failed to unite with bone in the usual time expected in a given patient, for a given fracture, in a given bone being treated with a given method. Union process did not cease but there is no average progress common for the respective fracture site. Timing is impaired in delayed union - it heals longer but it still does. Union is influenced by : type and the place of the fracture, blood supply, individual organism, age and condition, reduction and stabilization of the bone fragments, permanent distraction, extent of the soft tissue damage. Longer immobilization for the doubled time is permitted. Callus size and quantity depend on initial displacement and instability of the fracture fragments.

Delayed bone union takes place in case of one or both elements are affected:

a) impaired vascularization on the fracture site, caused by trauma

b) diminished mechanical conditions for the bone fragments stability

It is of crucial importance to choose method for the fracture management; method providing sufficient stability and early patient mobilization, weight bearing. It was found that majority of patients with delayed fracture union was not allowed limb mobility or weight bearing. Majority of authors do not consider surgical treatment necessary in this phase, unless all possibilities for osteogenesis stimulation are exhausted. (45,56,76) Stimulation of the osteogenesis in delayed union is achieved by:

1. Biocompression, if bone fragments are stabilized with external fixation;
2. Functional cast, providing axial micromovements
3. Gait with full weight bearing
4. Electrical stimulation

Ideal rigidity necessary for the optimal bone union is still unknown. Micro movements - 0,5 to 1 mm enhance bone mineralization and fracture stiffness; whilst micro movements over 1 mm lead to delayed union and non union, pseudoarthrosis.

Delayed union is confirmed with radiography and with manual testing of the callus. On clinical examination there is moderate pain on manual tests; bending, weight bearing…

2. NONUNIONS - PSEUDOARTHROSES

It is generally accepted that nonunion is the state of healing of the fracture when the natural biological healing process has ceased. , with therapeutic intervention required of the fracture indicate process in fracture healing when biological process of healing ceased. If union did not occur after ix months following injury, no primary or secondary bone consolidation is achieved and osseous union is not expected without surgical interventions: bone grafting, re-osteosynthesis…[26,37,69,70,73] Surgical therapeutic intervention is required to achieve osseous union.

Controlled or limited instability possibly lead to increase in callus formation. Uncontrolled or excessive instability can delay or impair solid bone union. The following factors influence stability or instability of the fractured fragments stabilized with external fixator: stuffiness of the given frame, mechanical properties of pins, pins holders, distance pin - bone. External fixator configuration (unilateral., bilateral, triangular) impacts on fracture fragments stability. AO School Behrens and al., (1983/1989) compare unilateral and bilateral frame concluding - there is a minor difference in pseudoarthrosis development following stabilization with unilateral or bilateral fixator. In sagital bending, bilatetal frame configuration is weaker; while bilateral frames more mechanical efficacy in two planes.

Term pseudoarthrosis indicates certain form of fracture nonunion within given period of time (tubular bone 6 - 8 months), with sclerotic bone ends, possibly demineralized and with medullar canal closed. There is an obvious cavity between such fragments, containing all elements of the join: joint capsule, synovial fluid and deformed joint surfaces covered with fibrous cartilage. Bone fracture healing process is definitely hindered. All processes tending at fracture healing are plainly stopped. Clinically, there is painless pathological motion on the fracture site, limb deformity and length discrepancy, contracture of the nearby joints. On the fracture site we find visible gap, defect varies in size, filled by connective and cartilaginous tissue, synovial fluid.

Common local factors influencing pseuddoarthrosis development are:

1. inadequate position of the fractured fragments;
2. soft tissue interposition between fracture fragments;
3. inadequate and insufficiently long immobilization;
4. allowed gait with axilar crutches without weight bearing on the injured leg; subsequently no positive pressure of the fragments promoting callus formation;
5. fixation material , with no biological and electrostatic activity towards the bone - impedes union;
6. infection;
7. during blood, open reductions of the bone fragment, there is a danger of infection, periosteumeal stripping (blood supply is impaired), which further impedes callus formation and promotes pseudoarthrosis. If no adequate stabilization is done, risk of pseudoarthrosis increases.

Most common systemic factors influencing pseudoarthrosis development are:

1. age of the wounded;
2. metabolic disorders;
3. general circulatory disorders;
4. chronic diseases

Pseudoarthrosis frequency in the peace-time wound is between 2,5 % to 10 %, and in open tibial fractures type III even up to 60 %. [23,76,78,90] In war surgery, nonunions and pseudoarthrosis account for 67 % of disability among patient with locomotor system injuries, where 40 % are complicated with osteomyelitis.[70,79,80] There are different results , in relation to the fractured bone in peace-time trauma , where percentage of nonunions and psseudoarthroses varies between 2,5 % and 60 %.[23,34,57,69,70,71, 73,81]

During previous war , in Clinic for the Orthopedic Surgery and Traumatology in Banjaluka, following primary surgical treatment, there was a need to stabilize fractured fragments in 2195 wounded (89,23%). In 2043 (92,43 %) there were comminuted fractures.

2.1. Classification of nonunions / pseudoarthroses

Judet divides nonunions / pseudoarthrosis to hypertrophic and atrophic; Ilizarov divides nonunions to stiff and loose.

A stiff nonunion corresponds to hypertrophic nonunion; there is usually a pain on motion of nonunion and a feeling of resistance to manual deformation at the fracture site. Roentgenograms of stiff nonunion reveal proliferative callus growing out of the fragments on both sides of the fracture line.

A loose nonunion moves easily during manual examination of the fracture site. The patient often experiences little or no pain. On roetgenograms, the fracture site may show the features associated with atrophic nonunion - no evidence of callus formation.

2.1.1. Hypervascular pseudoarthrosis

Pseudoarthrosis / nonunions can be radiographically and morphologically classified on the basis of the blood supply to the fragment ends of the unhealed fracture at biologically viavle (vital) and biologically non viable (avital) fracture sites (Weber and Cech, 1973).

Hypervascular (vital), (Fig. 15) , competent for biological reaction, no need for bone grafting, only rest of fractured fragments should be ensured. Feature of these pseudoarthrosiss is an adequte vascularization of bone ends!

Fig. 15.

Viable, biologicaly valuable pseudoarthroses are:

a) Hypertrophic pseudoarthrosis -"elephant foot" , characterized by hypertrophic, excessive callus, which in 90 % of cases results from the insufficient bone fragments stabilization or premature weight bearing, commonly following conservative treatment. Hypertrophic pseudoarthrosis possesses significant osseous regeneration and adequate vascularization.

b) Hypotrophic pseudoarthrosis - "horse foot" is with moderate callus (with minimal osseous regeneration), with possible small sclerozation of the fractured fragments, all well vascularized. Occurs in moderately unstable fractures, stabilized with AO plates, screws…

c) Oligotrophic pseudoarthrosis - develops following inadequate reduction, presence of the small fragments and inadequate internal fixation. With no osseous regeneration, bone ends are rounded, resorbed, retracted but blood supply is preserved. On radiography, callus and ends hypertrophy are missing. This pseudoarthrosis is often classified in atrophic pseeudoarthroses. (Fig. 16)

Scintigraphic examiniation indicate proper biological activity, increased in comparison to healthy limb in hypervascular pseudoarthroses. Sclerotic deposits on bone ends are good indicator of vascularity and hypertropic callus is is reaction

Fig. 16.

to instability as cause to nonunion. Conservative methods can not ensure absolute rest for the fractured fragments. Further, no primary healing is ensured without radiologically visible callus. Intimate contact between fractured bone is achieved by anatomical reduction and further increased with compression. This results in impact of bone fragments, bone continuity and direct transfer of forces, from one fragment to another, not via osteosynthetic material. This alos prevent breakage of the osteosynthetic material, pseudoarhrosis or loosening. Process is first described by Danis, in 1949; later confirmed by Schenk, Willeneggera and other authors.

Secondary healing is stimulated by relative motion of the bone fragments ends, allowed by cast immobilization, traction or external fixation. Existing fracture fissure conditions healing via periosteumal bridging callus. (Fig. 17)

Fig. 17.

Upon stabile fixation in hypertrophic pseudoarthrosis, fusion of bone fragments is very soon achieved with hondral and dezmal ossification.

Non-osteogenic, partially osteogenic site should with decortication and refreshemnt of the wound edges be transformed into highly osteogenic site. Decortication is done with sharp and thin chisel, 05 to 2 cm wide, cortical lamellas are taken off in such fashion that they stay in tight contact with periosteum and soft tissue for vascularization. It covers 2/3 of cortex and up to 10 cm of the bone fragment length. It depends on the type of pseudoarthrosis and bone anatomy. Newly formed viable osseous wrapping produces fixation callus with rapid ossification, with or without cancellous bone graft. Decortication is first described by Dunne (1993), and Judet brothers (1965) experimentally proved biological significance of the union stimulation.

In my experience, best results in dealing with hypervascular pseudoarthroses I had using method of compression - distraction, decortication both partial or complete.

Bone grafting and resection of cartilagineous and osseous tissue is usually not needed in hypertrophic pseudoarthroses. Stabile fixation is achieved with extrafocal placement of fixator wires or pins, while frame construction (triangular, quadriangular,semicircular) ensures spacial correction of deformioty: varus, valgus, antecurvatum, discrepancy…

In moderate cases, application of external fixation and problem solving are done in single operation, in complicated cases - gradually following surgery. Achieving adequate stabilization, full weight bearing is immediately permitted as well as ROM exercises. Osseous consolidation is achieved in 1,5 -3 -5 months.

2.1.2. Avascular pseudoarthroses

Avascular, inert , avital pseudoarthroses have no potential for consolidation since, from the biological point of view, ther are no conditions for union. As frequency and development of hypervascular pseudoarthroses is commonly related to conservative treatment, so are avascular pseudoarthroses in relation to fracture treatment with plating and internal fixation. It is understandable, if primary trauma is aided with artificial trauma (incision, periosteumal stripping, osteosynthetic material, infection), there are hardly biological condition required for union. Avascular pseudoarthroses are grouped into:

a) wedge-shaped / torsion pseudoarthroses - characterized with presence of the intermediary fragment, usually attached to one main fragment, but not for the other. Vascularization is reduced or fully absent.

b) comminutive pseudoarthroses - characterized with presence of few intermediary fragments which are necrotic, with no signs of union. Vascularization absent.

c) defect pseudoarthroses - characterized by loss of diaphyseal fragment. Bone ends are viable, with time necrotic. Bone defect does not permit union.

d) atrophic, dead pseudoarthroses - develop when intermediary fragments disappear and soft tissues loose their osteogenic potential. Bone fragments become osteoporotic and atrophic.

Pseudoarthrosis poses an absolute indication for treatment!

Treatment of the vascular pseudoarthrosis of the long bone is conditioned by: type of pseudoartrosis, bone loss extent, stiffness of the nearby joint, impossibility to provide stabile fixation (pseudoarthrosis next to the joint), infection…

In last decade, internal stabilization in pseudoarthrosis treatment is less and less used, the only dilemma now is the choice of external fixator. External fixation ensures anatomical reconstruction, correction and treatment of deformity, extrafocal stabilization, graded weight bearing, early mobility for limbs and joints.

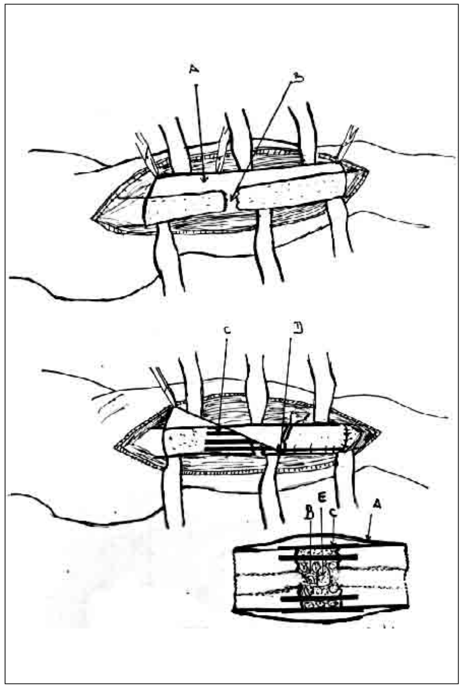
In case of long bone pseudoarthrosis, with bone defect over 5 cm, with avascular fragments associated with soft tissue loss, method of compression and distraction is treatment of choice . It ensures:

1. stabilization with physiological limb length and treatment for pseudoarthrosis with external transport in soft tissue loss;
2. stabilization with physiological limb length and treatment for pseudoarthrosis with internal transport in salvaged soft tissue;
3. temporary limb abbreviation (resection of the avital bone ends); provides good contact; with corticotomy and distraction it ensures correction of limb length discrepancy and treatment for limb pseudoarthrosis.

Considering extent of the bone loss and risk for stability , defect should be filled with osteogenietic substance. Defect up to 5-6 cm are dealt with cancellous, corticocancellous autografting….

Pseudoarthrosis and bone are exposed first, then periosteum is opened (a) and the cover of pseudoarthrosis longidudinally. Periosteum and cover are prepared longitudinally, in the form of flap on one side and callus of pseudoarthrosis is made even with osteotome (b) Then, bone graft is placed on de-periosted bone. , which is then covered and fixated by periousteum flap. (Sch.4) Autograft may be cancellous, iliac grafts, thick up to 2 mm, long enough to bridge bone defect (c) . They are places as palisades into a pseudoarthrotic center, along with fragments decortication. Rapidly responds to mechanical stresses, start no immune response and soon reaches the size and the strength of the host segment.

This method is first described by Phemister in 1947; he did not emphasize either immobilization of bone fragments or osteosynthesis in radiologically registered sclerozation. Medullar canal is obstructed due to interposed tissues, pesudoarthrotic site should be drilled according to Beck, or medullar canal should be open by longitudinal drill. Forage supports vascularization of pseudoarthrosis zone and ensures osteoblastic activity. Some authors recommend parafocal osteotomy , done 5 cm proximally nd distally, subperiosteally from the pseudoarthrotic focus. They stimulate osteogenesis, on basis of osteoinductive and osteoconductive properties.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Dieffenback-Beck method is indicated unless some soft, fibrous tissue is interposed between bone fragments and interfragmentary space is free. Method consists of multiple drilling into both bones, in interfragmentary space so drill or needle passes through medullar canal of both bones. Such perforations should be carried out on about 25 to 30 places:

• transcoutaneously - inserting needle or drill obliquely through the skin, bone and pseudoarthrosis;

• by an open method where soft parts up to the bone and pseudoarthrosis remain opened.

With this method osseous tissue will be introduced into interfragmentary space as autografts and thus stimulate bone healing.

Kirscher's method releases pseudoarthrosis from the soft tissue. With chisel proximal and distal part of the bone are slightly cut up to pseudorthrrossis, chopping it on more sites and bridging bone defect.

Lexer's method for pseudoarthrosiss resection and bone grafting is indicated when fibrous (scar) tissue is interposed between fragments, associated with dislocation and bone defect.

Pseudoarthrosis is resected into a healthy bone:

• en block

• pseudoarthrosis is divided: all scar elements are removed, and peaks resect up to the healthy osseous tissue; where medullar canal must remain open.

If fragments can approximate, they should be stabilized by AO-plate, Kuntscher pin, gradual bone resection…If bone fragments are distanced, then bone defect should b filled in by bone graft which may, to proximal and distal bone ends, be fixated in various ways.

Nowadays, autografts are not used for mechanical stability, since fragments are stabilized by weather internal or external fixation.

VI - BONE DEFECT

Bone defect understand loss of the osseous tissue along its longitudinal axis . (Fig. 18) Limb function is not only impaired in diaphyseal defect, defect of the entire bone circumference then also in significant bone lose at the bone ends, leading to a change in bone stability. Bone defect in gunshot wound are result of removal of loose bony fragments and resection of devitalized bone fragments during primary surgical treatment or in subsequent surgery.

Fig. 18.

1. HISTORY OF BONE LOSS MANAGEMENT

Spontaneous filling of bone cavities and bridging of large defects of the long tubular bones in humans is not to be expected, irrespective of weather these defects are due to trauma, posttraumatic pseudoarthrosis, excision of benign or malignant tumors, insufficient growth in lengthening operations or following primary surgical wound management with partial or complete bone loss. In all such cases, there is an increasing demand for bone grafts in repair surgery (limb salvage). Transplantation of autogenous bone is today the elective procedure. It is usually carried out in combination with stable internal or external fixation of the bone fragments.

In history of medicine development, understanding and experience on fractured bone consolidation and bone loss management underwent many changes.

Hypocrite (Fig.4) thought that callus is formed form the bone marrow and Galleon believed that osseous fragments are glued with hardening bony fluid. [12,15]

Dutch, Antonius de Heyde, carried out experiments on frogs and gave first significant observations on callus formation on the fracture site and on haematoma surrounding callus. [15,17]

Dutch surgeon Job Van Meekeren, in 1668 described the first procedure of the bone grafting taken from a dog to repair skull defect in soldier. Grafting succeeded but church took an extremely negative attitude towards the whole procedure. [15,17]

Anthony Van Leeuwenhoek, in 1674, reports on the osseous structure and many consider this to be the origin of idea on bone transplantation.

In his works from 1740 Dumambel believes that callus develops from the bone marrow and periosteum and Dupytren distinguishes primary callus from the definitive one.[9]

In 1858 Wirchow states that all tissues participate osseous reparation; bone with periosteum, he recognizes significance of the stratum osteogenum subperiosteumale. [8,9]

In experiments with rabbits and young dogs, Frenchman Ollier proves that autografts are vital, capable of survival and growth in favorable environment He propagates the osteoblastic theory, stating that transplanted osseous cells actively contribute to the bone regeneration. He demonstrated formation of the new bone from the periosteum. [15,16,17]

Barth, in 1893 postulated the theory of induction, assuming that the graft did not survive but stimulated the pluripotent mesenchymal cells of the host tissue to differentiate into osteogenic cells which caused "creeping substitution" of the graft. [16,17]

The first autografting in clinical practice is performed by German Phillips von Walter , in 1820.

In 1863 Wolff definied osteoplasty as an operation in which "Bone or bone stimulating tissue is implanted in the body in order to effect permanent existance of bone at that site." Finding base in animal experiments, he expressed hope that it would be possible to treat both congenital and acquired defects using autogenous bone grafting in the future.[24]

Scott William Macewen in 1880 performed the first bone allograft.

In 1889, Seydel close a 20 cm defect in the skull by repeated grafting of autogenous periosteumeal bone flaps from tibia. [19,24]

In 1893, Schmitt reported an operation by Brigmann in which the later succeeded in bridging a 12 cm tibial defect, resulting from resection of sarcoma, by insertion of an autogenous fibular graft. [24]

German Arthur Barth in 1985 publishes research on bone transplantation in German Anatomical Magazine and for the first time mentions the term bone transplantation.

Since Payr`s first publication in 1908 "On osteoplastic substitution in cases of resection of the jaw (maxillo-mandibular defects) using parts of the rib by means of pedicled chest flaps or free grafts", autografting of the rib has become a well-known and frequent operation in maxillofacial surgery to bridge defects of the mandible (Lexer, 1924; Longacre and de Stefano, 1975; Schmelzle and Schweizwer, 1977). [14, 15, 17, 24, 32]

In 1905, Huntington emphasized the advantage of using bone grafts with own vascularization in repair of big tibial defect. Carrel, in 1908 published the article "Results of the Transplantation of Blood Vessels, Organs and Limbs" marking the birth of vascular surgery.

On the basis of histological investigations carried out on biopsy specimens and grafting in experimental studies, Axhausen confirmed in 1909 that in fresh, autogenous bone graft covered by periosteumeum there was necrosis of the bone ends, as established by Barth, but that the periosteumeum survived to a large extent and actively influenced osteogenesis. [70]

In 1910, Dobrotworski closed a cranial defect for the first time using a rib which has been split longitudinally, stating: "The rib offers extraordinary advantages and convenience as a covering for cranial fractures. It can be successfully used as a bone substitute in many cases of defects of the limbs." The conclusions he published, reporting on four successful cranial defects closing are thoughts to be the beginning of autogenous bone grafting as an internationally recognized, regular procedure in surgery and orthopedics. [7,11,26]

Brown (1913) recognized that intramuscular or subcutaneous transplantation of periosteum would not generate new bone while Albee in 1919 reports on 1600 successful bone grafting procedures.

Urist and colleagues recognized osteoinduction or presence of chemical mediators inducing regeneration of the osseous substance.

Barth in German and Curis in USA, in the onset of 2oth century, independently of each other, published works on bone transplantation. Barth described absorption of dead tissues in bone graft and new bone growing into graft from the surrounding viable bone. Curtis described processes of graft resorption and successive ossification , termed "creeping substitution" (1914) by Phemister. [24,70]

In 1914, Lexter and Phemister systematically reported possible applications of autogenous bone grafting. They demonstrated the universal clinical application of the compact tibial graft complete with periosteumeum which has been named after them,

Lexer recognized the important role played by stability in acceptance and healing of cortico-cancellous bone grafts. He introduced the terms: non-osteogenic, partially osteogenic and highly osteogenic place with reference to the host site. [15,17,19,24,70]

Matti, in 1932 and 1936 described autografting of pure cancellous bone in the treatment of pseudoarthrosis. Despite very positive results, this procedure did not become established.

The use of autogenous cancellous bone only became possible with the advent of modern methods of internal and external fixation of the skeletal fragments. Nowadays, autogenous cancellous bone is the substance of choice for bridging and filling defects, particularly in cases of infected fractures and pseudoarthroses. (Burri, 1974)

In 1935 Krompecher proves primary angiogenic bone development in mechanically neutral area (skull of the rat embryo). He assumed that such direct angiogenic bone formation may be possible in fully immobilized fracture.

Inclan, in his works, says that homologous cadaver grafts can be used in repair of significant bone defects (1942). These works are messengers of the "bone bank". The same year Levander demonstrates that proliferation of mesenchimal cells induces bone formation. [17,24]

Ilizarov (1951) developes and improves now world-wide accepted, method of distraction osteogenesis, method for production of unlimited amount of a living bone directly with special osteotomy and by controlled mechanical distraction of the bone. [43,44,45,46,47]

Trueta and Cavadias (1955) proved that subperiosteumal vascular proliferation plays the crucial role for periosteumal perfusion in new bone formation.

Powels, 1956 recognizes the importance of mechanical load, forces vectors and direction on callus formation and remodeling.

Schenk in his work from 1963 discusses the possibility of direct, contact bone union, followed by full stability of bone fragments and rich vascularization,.

Perren, in 1969 proved that callus size depends on extent of interfragmentary motion - micro motion causes bone resorption.

In 1977 Burri, compressing cancellous pieces with special tool, forms solid cancellous cylinders, tables for filling uninfected bony defects. Compresses graft, shaped and produced as desired, has high osteogenic power, rapid revascularization despite such compact structure. Burri reports on compensating bone defects up to 10 cm in long bones.

Popkirov in 1980 uses cancellous bone resilience to infection, grafting calm osteomyelitic defects of diaphysis and infected pseudoarthroses. Such bone grafting is followed by leaving wound open to the secondary healing and method is named **- open bone grafting.**

In the last two decades, bone grafting procedures have taken on a new dimension due to the additional possibilities offered by microsurgery. Following the successful animal model, free vascularized bone grafts are being used in humans. Animal experiments included transplantation of bone grafts with proper arterial and venous systems by using microsurgical technique (Strauch, 1971, Haw et all, 1978, O`Brien, 1977, Ostrup et al, 1974).

In 1975 Taylors and colleagues reported on success in using vascular fibular graft for huge segmental tibial defects,. Ueba and colleagues transplanted first vascularized fibular graft in Japan in 1974. Gilbert and colleagues in 1979 include mid third of fibula and nutrient artery whilst Wood prefers Gilbert's technique since muscular cuff of Taylor's graft undergoes necrosis thus preventing vascularization of osseous host bed in vascular complications. (2,4)

In due time orthopedic surgeon will have "bottled bone graft " on disposal. Biological research laboratory obtain the permission from the FDA for clinical testing of the B.M.P. product (bone mending protein). B.M.P has given excellent results in pre-clinical trial. It was used in comminution fractures and bone defects. Currently, in implant surgery palacos is used. B.M.P. would secure the implant by stimulating the bone ingrowth around it. Preparation would have usage in orthopedic surgery, neurosurgery… In dentistry, application of B.M.P. on sensitive pulp would enhance dentine formation as a natural protective barrier. Researchers involved in B.M.P. development suggest that preparation will be available in pills, injections and paste. B.M.P. will be applied locally, with an injection, on bone loss or delayed union place (26). Applied, B.M.P. would promote normal bone union." Protein weakens healthy cell indicating the time for start and bony regeneration".(74) It is confirmed that B.M.P. , via unknown mechanism or factor influences healthy cell of the surrounding bone tissue, migrating into bone defect. Bonding to B.M.P., these cells become hondocite like and B.M.P. stimulates production of the cartilaginous tissue.

With time, calcium is deposited into cartilage and the new bone acquires shape and structure of the original bone.

Since B.M.P. stimulates bone growth by inducing cartilaginous tissue first, research is currently focused on regeneration of the impaired joint cartilage.

As foreseen, FDA USA will license B.M.P. in 7 to 10 year for general use.

Only in United States there are 100.000 bone transplantation a year. This number places bone on the second frequent (after blood) tissue transplant. Yet, these secondary operative procedures carry a documented complication rate of 3 - 30 %.

2. CAUSES TO BONE DEFECT

Causes to bone defect can be: war wound, chronic osteomyelitis, tumor resection, injury in peace-time trauma…All these causes t bone loss can be associated with varying degree of soft tissue destruction. Bone defects due to osteomyelitis usually have satisfactory blood supply on host site, or more satisfactory if compared to bone defect following injury.

Musa and colleagues in 1988 publication consider defect to be a bone loss of 5 mm and more, proposing the following classification:

1. primary defect occurring in moment of wounding (injury) when projectile (trauma) with kinetic energy blows the tissue away.

2. secondary defect developed following primary surgical treatment of the war wound , removal of bone fragments with stripped periosteum.

Fig. 19.

3. surgical defect resulting from bone resection; tumor resection or sequesters removal (Fig.19).

On radiography of long bones fractures, diastasis, in shape, extent and distance between fractured fragments can often can look as a bone defect. Distasis can be larger then bone defect but it is usually smaller. For superposition of shadows on radiography, inexperienced orthopedic surgeon could mistake diastais for bone defect.

3. EXTENT OF BONE DEFECT

The choice of optimal repair procedure should consider extent of given bone defect , the most appropriate surgical technique - best result and liest discomfort for the patient as well as complication rate.

Only the choice of optimal reconstructive techniques as cancellous bone grafting, vascularized bone graft, distaction callus or amputation, will lead to the optimal results. Further on, in decision making the following should be considered: defect site (upper or lower limb) , metaphysis or diaphysis; defect type (partial or segmental). (Fig.20)

Choice of optimal graft is specific for each bone defect, demanding a multidisciplinary approach.

For defects up to 3 cm, bone grafting is most simple and most commonly used method. Most authors suggest bone grafting as a treatment of choice. Many authors agree that bone loss up to 6 cm can be bridged with massive cortico-cancellous autograft. [34,23,67,70]

For 6 to 10 cm bone defects commonly chosen technique is vascularized osteoperiosteumal graft form the iliac bone, described by Stock and colleagues.

When dealing with bone defect with more than 10 cm in size, vascular fibular graft is the only option, since fixation of iliac bone graft would lack sufficient mechanical strength. [34] Microvascular fibular graft placed in bone

Fig.20 - Metatarsal bone defect; bone defect repair with cortico-cancellous bone graft

defect up to 10 cm shall bridge with new bone twice as fast as in the case of simple autogenous or homogenous avascular cancellous bone graft, in two or three subsequent surgeries. (Zweipper and associates)

Distraction osteogenesis is a method of producing unlimited quantities of living bone directly from special osteotomy (corticotomy) by controlled mechanical distraction. The new bone spontaneously bridges the gap . Ilizarov (1956) introduced this technique which is more and more being adopted since more then 18 cm of new bone can be regenerated from a single operative intervention. [41,42,43,44,48]

Bone transportation means regeneration of intercalary bone defects by combined distraction and transformation osteogenesis. The transport segment is usually the entire cross section of bone but it can be a partial fragment to fill a partial gap, bone defect. In the same act, on the other fragment end distraction osteogenesis should produce new tissue that rapidly remodels to a new bone. [41,42,43,44,48]

VII - AUTOGENOUS BONE GRAFTING

INTRODUCTION

Nowadays, most commonly used methods for the bone defects reconstruction are:

1. bone transplantation or bone grafting using:
   - autogenous / autologous bone graft;
   - homologous bone grafts / allografts;
   - heterologous bone grafts
2. transfer of the vascularized bone as a vascularized graft from :
   - iliac bone
   - fibula.

Chosen method will depend on surgeon's skill and the following factors:

1. etiology (trauma, tumor, osteomyelitis…);
2. size of defect (up to 3-5-7 cm or over 10 cm);
3. defect site (upper or lower limb, metaphysis or diaphysis)
4. type of defect (partial or segmental)

Favorable outcome depends on choice of the optimal reconstructive procedure, then optimal, timely reconstruction with repair done in one or subsequent acts.

The choice of the procedure ensuring the best results , liest complication degree and most comfort for the patient presents dilemma.

Technique of bone transplantation became basic part of fracture management in orthopedic surgery. Successful bone transplantation will depend on adequate knowledge of indications and contraindication, as well as biological principles and potential complications.

Bone grafting or bone transplantation understands placement of the part of the bone from the donor site to the host site - in the same person, from one person to another or with donor and recipient as different species. Considering the relation between the donor and the recipient / host , bone grafts are divided into three groups:

1. Autologous bone graft - An autograft is tissue that is transplanted from a donor site to a recipient site in one individual, autograft is histocompatible with the host immune system. Rarely, there are iso-graft, as in the case of identical twins. In autograft, genetic difference is ruled out thus genetic incompatibility as well. Disadvantage of autografts is the limited amount of bone and the length of the treatment. Cancellous bone autograft is an universal aid for each orthopedic surgery aiming at bone consolidation or bone healing. Use of the autograft can mean a difference between union and nonunion.

2. Homologous grafts - allografts is a tissue that is transplanted from one individual to another individual of the same species. The advantage of allografts are is total amount available and blood bank storage. Shortcomings are genetic incompatibility; host immune system recognizes the foreign cellular antigens of the donor graft and mount an immune response. Preserved allograft, such as cortical bone treated by freezing, freeze-drying, autoclaving, chemical preservation irradiation, is nonviable and is referred to as an alloimplant.

There are also bone substitutes on the market that can be used to extend cancellous grafting material (OSS-transplant; Miter, Columbus,OH…)

3. Heterologus graft is a bone graft obtained from and planted to divergent biological species. The advantage are inexhaustible sources but genetic mismatch is great in comparison to the allografts.

1. BIOLOGICAL PRINCIPLES OF AUTOGENOUS BONE GRAFTING

The bone defect is evaluated for treatment according to the following:

1. vascularity of the host site
2. stability of the host site
3. cause of the bone defect
4. extent of the bone defect

1.1. Vascularity of the host site

Valuable tools for the assessment of the vascularity of the host site is given by Lexer (1924) and Eithel (1980). The classification based on the work of these authors is also applied to the description of trauma to bone and soft tissue in fresh fractures and in pseudoarthrosis. All sites are divided into three categories:

1. highly osteogenic
2. partially osteogenic and
3. non-osteogenic

1.1.1. Highly osteogenic site

The injury and subsequent fracture has not led to any significant damage to the blood supply to the host site. No extensive areas of soft tissues have been stripped and there is no hypovascularisation. The devascularisation due to the accident is more less compensated. Increased tissue perfusion enhances flow of blood rich in oxygen and allows to antibiotics and other drugs to reach the site of action. By strengthening some bodily internal defenses against infection within the affected area "non-osteogenic" site will convert into "partially osteogenic site" then "highly osteogenic site". This is a situation for closed fractures in which there is no dislocation and no damage to the soft tissues which would compromise the blood supply.

1.1.2. Partially osteogenic site

Vascularisation is impaired! The endosteal and periosteumeal blood supply to the cortex and the medullary vessels are not functioning at all, or only marginally. There is reduced perfusion of the soft tissues. The conditions correspond to those of a first or second degree open or closed fracture with extensive soft tissue contusion. (Fig. 21)

Fig. 21.

In open fractures blood supply is impaired by injury itself and it is no surprise that , under equal mechanical conditions - stabilization of the bone fragments , open fractures require more time for healing.

1.1.3. Non-osteogenic site

The blood supply to the bone and soft tissues has been destroyed! Such injuries are found in war wounds as well as in case of third degree open fractures.

1.2. Stability of the host site

The choice of the graft is decisively influenced by the stability of the host site. In the case of stable defect graft need not to offer any additional stability. The main objective is to fill or to bridge the defect with the osteoinductive material. The graft must withstand pressure forces whilst bending, tensile forces are neutralized by external fixation or tension band plating, depending on choice for the fragments stabilization.

Unstable defects are observed in situations of bone loss in an area of mechanical loading. The continuity of the bone is interrupted. Additional complications may arise in cases of impaction and compression fractures. Compressive fractures involve the collapse of the cancellous bone. Resorbtion of the bone creates defect which has to be filled with autogenous graft and stabilized with internal or external fixation. In exceptional cases, in which pressure-resistant bicortical or tricortical cortico-cancellous bone has been used and the tension side of the bone is intact, fixation may not be necessary.

Once the articular surface of an impaction fracture of the joint has been restored, a subhondral defect of the cancellous bone remains. The articular surface will be compacted under pressure if the defect is not filled. Insertion of pressure resistant bicortical or tricortical cortico-cancellous graft into defect subchondrally will achieve stable reduction, especially when combined with internal or external fixation as in the majority of cases.

1.3. Phases of autogenous bone graft healing

The incorporation of bone graft is similar to the process of fracture healing. This process include induction, inflammation, soft callous formation, hard callous formation and remodeling. In large grafts , many stages are present at any one time in different portions of the graft.

The success of bone grafting depends on the active participation of the graft in reparative osteogenesis. Apart from filling the defect and providing mechanical support, the functions of the graft include stimulation of osteogenesis, this is osteoinduction. The conditions for successful grafting are early vascularisation and a vital graft. These conditions can only be entirely satisfied by fresh, autogenous grafts at a highly osteogenic site.

2. EARLY OR INFLAMMATION PHASE

The first phase begins with the infiltration of blood into the graft, i.e. into spaces between bone particles. According to Tonna (1961), the adjacent soft tissue contains dilated vessels, plasma exudate and granulocytes. There is activation of host osteoblasts and differentiation of primitive mesenchymal cells into chondroblasts and osteoblasts. Osteoblasts are derived from the stem cell - population present in the marrow, at a rate of 1 per 106 white blood cells and also to some extent in the periosteumeum.

The source of these cells may be endosteoum, periosteumeum, marrow or connective tissue. The stimulation may be electronegativity, relative hypoxia, acidosis or release of lysosomes or kinins. This leads to an increased number of polymorphocellular elements, osteoclasts on the surface of the host bone and the bone graft. (Dambre, 1981)

Mechanical factors are important in bone graft incorporation. Osteoprogenitor cells develop into osteoblasts under the influence of compressive forces; fibroblasts under tension forces and chondroblasts under the application of shear forces at the bone-graft interface.

2.1. First osteogenic phase

The first signs of osteoblastic activity may appear after 3 - 4 days on the endosteal and periosteumeal surface of the host cortex and somewhat later on the surface of the transplanted cancellous chips. Their role is to lay down a new bone. Osteogenesis can also be induced by metaplasia in muscle pouches by decalcified bone matrices. This is thought to be stimulated by a bone morphogenic protein (BMP). Vascular endothelial cells play an active role in remodeling by invading the graft bed with capillaries, supplying nutrients and possibly providing access to the graft for circulating precursors of the above types of cells. According to Lacroix (1971) the periosteumyal fibrous layer detaches itself as the first osteoblast develop in the cambium layer of the periosteumeum. The sudden onset of osteogenesis is an indication that there are surviving cells on the surface of the graft which are capable of generating bone.

2.2. Second (induction) osteogenic phase

After 2-3 weeks, a phase begins which is decisive for further repair processes. Proliferating mesenchimal vascularized tissue has invaded the graft from the host bed. The vessels originate in the medullar region and grow radially. The pluripotent mesenchymal cells differentiate to osteoblasts on the surface of the transplanted cancellous bone chips. The primary osteogenic phase is overshadowed by the induced bone regeneration.

2.3. Formation of woven bone

Histomorphologically, the osteoblasts are organized in a single layer in both the first and second osteogenic phases. Osteoblasts transport the matrix components to the surface of the basal membrane and along the outer margins. The deposition of bone cells along the edges of the adjacent cells causes the cells to overlap creating a bony layer to the previous direction of growth. This is extended by newly formed osteoblasts which are deposited on the newly formed margins. A network in which the vessels lie is gradually formed by repeated branching and changes of orientation.

2.4. Formation of lamellar bone

Woven bone grows fast and provides a scaffolding for the lamellar bone. The osteoblasts on the bone chips deposit osteoid. Due to appositional growth of lamellar bone, the trabeculae widen and the spaces between the narrow until the Haversian structure has been formed. The transplanted cancellous bone is mostly removed by osteoclasts , but it is also partially incorporated. Diffuse, unstructured bone results which consists of both lamellar and woven bone.

2.5. Haversian remodeling

Remodeling of Haversian structure only seem to start at the time of mechanical loading of the unstructured bone. The mechanism which directs Haversian remodeling are vectors of the compression forces.

3. TRANSPLANTATION AND BONE IMMUNOLOGY

Any orthopedic surgeon who undertakes the task of bone grafting must be familiar with basic principles of immunology. There is rejection reaction in the vast majority of organic allografts .

The rejection response can be divided into:

a) cellular and

b) humoral processes.

The cellular elements participating these processes are:

T-cells,

B-cells and

macrophages.

T-cells can be divided further into:

helper (TH),

suppresser (TS) cells and

cytotoxic cells.

The humoral components include system of:

- complement and
- antibodies.

Several basic types of rejection have been described. The process of rejection is started if graft antigens are recognized as foreign by host immune system. Several types of antigens on a graft can trigger such a response.

Also, if preformed antibodies against the graft are present in the blood of the host, hyperacute rejection will result. Often, if ABO blood groups are not matched, antibodies to non compatible ABO antigens are circulating in the blood of the host and trigger this rapid response when they come into contact with the graft. This type of rejection is no longer seen, because crossmatching is performed.

The processes of acute and chronic rejection occur when there is a mismatch between graft and host at the major hystocompability complex (MHC). The MHC is a set of genes located on chromosome 6 which codes for the histocompability antigens. These antigens are proteins and glyckoproteins produced by cells and then often displayed on their surface. These antigens are divided into:

CLASS I (serologically determined or HLA-A, B and C antigens);

CLASS II (lymphocyte determined or HLA-D antigens).

The genes coding for Classes I and II antigens lie close to each other on chromosome 6., Class I antigens may be determined within a matter of hour using classic tissue typing techniques. Class II takes 3 to 4 days to perform mixed lymphocyte culture since Class II antigens cannot be determined by serological means.

Acute and chronic allograft rejections are largely mediated by cellular mechanism as well as by humoral components. Acute rejection which occurs within days to weeks after transplantation, as opposed to chronic rejection which occurs by a similar mechanism but months to years later.

Lafferty and Prowse have advanced a two-signal model for lymphocyte activation to explain the phenomenon of rejection. While allogenic graft MHC antigen-binding to a host T-cells provides the first signal , the second signal is provided by interleukin I(I-II) which is released by the graft APC when their MHC antigens are engaged. When both signals are present, the host T-cell becomes activated and mounts a rejection response. Once a T-cell becomes activated it will recruit the remainder of the immune system and destroy any cells labeled with the Class I or II antigens to which it has been sensitized, resulting in the destruction of all nucleated cells in a graft.

If only the first signal is provided, tolerance may result. This will occur if the APCs, which express Class II antigen , are removed from the graft. It has been demonstrated in endocrine glands that removal or inactivation of the APC passenger cells and endothelium prior to transplantation will result in indefinite graft survival.

The incorporation of bone graft is similar to the process of fracture healing . However, this process is slow when allogenic, heterogenic or pretreated bone is involved due to a low-grade immune response and/or due to a lack of osteocytes in the graft. The antigenicity of different cell types within a bone graft vary. Marrow elements are the most antigenic. They contain cells termed passenger cells which, if eliminated, cause a significant reduction of graft immunogenicity. Among the passenger cells are antigen-presenting cells (APC), such as macrophages or dendritic cells, which are probably the most potent stimulators of the immune system.

Trombosis of the micro-circulation and eventually the pedicle of vascular grafts may be the end stage events of graft rejection. Osteocytes do not stimulate lympocytes , are less immunogenic than marrow elements or endothellium and before vascularized bone allografts become ischemic osteocytes show marked ultrastructural damage at 3 days. Hondrocytes are quite antigenic but cartilage is an immunologically privileged tissue due to its matrix of proteoglycanes through which antibodies and lymphocytes are unable to pass. The crucial difference between other organs and bone is that despite being dead a bone graft can still function since it provides structural support, as well as "scaffolding" that may eventually be incorporated into live bone by process of creeping substitution.

3.1. Altering rejection response

In order to reduce the intensity of graft rejection, one can manipulate in one of three ways:

a) by altering the host;

b) by altering the graft;

c) by maching them more favorably.

a) - Altering the host

Immunosupression has not been used clinically in bone grafting because the significant side effects of this therapy are not believed to be justified for limb savage. However, laboratory data d indicate that immunosuppresssants improve bone graft incorporation. Maximum immunosuppressive activity occurs if administered just prior to antigen challlenge.

b) Altering the graft

Climan and al. showed that freezing an allograft decreases the antibody response while Elves found no evidence of humoral response at 8 weeks to frozen, freeze-dried or irradiated grafts.

The recipient's cellular response appears to be between fresh autografts and allografts but creeping substitution occurs late compared to fresh autografts and fresh allografts. Irradiation of vascular grafts has resulted in some a amelioration of the rejection response in visceral and vascularized bone grafts but has shown to have minimal or no effect on incorporation of avascular bone allografts. Of all alternatives , frozen allofgrafts are ones mostly used, since immunogenicity is dfecreased and the cartilage remains viable to some extent. It is prepared by immersing the cartilage in glycerol and slowly freezing the allograft to just bellow 00C. Then, it is quickly frozen down to -800C and stored there for as long as necessary. If treated in this way, ninety percent of isolated hondrocytes remain viable but due to slow penetration of cryoprotectants into intact cartilage, chondrocyte survival is much lower if they are not isolated first.

c) Matching host and graft

While in visceral organ transplantation tissue typing and cross-matching is standard, in bone transplantation this has not been done despite evidence that there is improved acceptance of frozen allografts by this procedure. This is due primarily logistical problems of maintaining a bone bank which must stock a wide variety of sizes of osteoarticular grafts to provide adequate match.

VIII - TYPES OF AUTOGENOUS BONE GRAFTS

The success of bone grafting depends on the active participation of the graft in reparative osteogenesis. Apart from filling the defect and providing mechanical support, the functions of the graft include stimulation of osteogenesis, this is osteoinduction. The conditions for successful grafting are early vascularisation and a vital graft. These conditions can only be entirely satisfied by fresh, autogenous grafts at a highly osteogenic site.

Bone grafts are defined according to the type of bone transplanted:

1. cancellous bone graft - autograft
2. cortical bone graft - autograft
3. corticocancellous grafts
4. vascularized bone autografts

Bone grafts can function as a source of osteogenesis or bone formation from donor cells that survive transfer and exercise mechanical role by acting as a weight bearing support placed into cortical defect.

Main features of the bone grafts include:

a) osteoinduction and
b) osteoconduction .

Osteoconduction understands creating template for the ingrowth of the new bone.

Osteoinduction understands ability of local induction in bone formation, but also ability to recruit cells with osteogenic potential and differentiation of mesenchimal cells in recipient bed, for the growth of the new bone.

1. CANCELLOUS BONE AUTOGRAFT

Conventional reconstruction / bone defect treatment with autogenous cancellous bone graft is widely used technique. Autogenous cancellous bone is used where cellular transfer, osteoinduction and osteoconduction are desirable but mechanical strength is not needed. Most of the authors agree that transplantation with autograft is a treatment of choice for bone defects up to three cm. It is most simple, the rate of incorporation is high whilst complication rate is low; results are as good as when other methods are used.

Cancellous bone can be defined as a porous cellular mass, consisting of irregular 3-D matrix of osseous sticks and plates., called trabeculas. It is a viable bone tissue, filling all free bone surfaces covered by osseous self-healing cells. It exercises ability to adjust its morphology in response to changes in mechanical surrounding; in other words it possesses phenomenon of bone remodeling. Features of the cancellous bone are:

- linear elasticity and possibility of remodeling following relatively minor distention;
- insufficiency of cancellous bone distention is independent of its density;
- growth asymmetry in relation to modulus sample increase (e.g. tension, compression)
- torsion function covers for tension and compressive function but with greater insufficiency of distention and lower strength.

1.1 Biology of the cancellous graft incorporation

Conventional reconstruction using cancellous bone graft is probably most commonly used technique. Log consolidation period and unpredictable phenomenon of resorbtion led to hypothesis that host site, graft bed, could be an important factor for revascularization and remodeling. Insufficient corporation is to be expected in irradiated, hypovascular and scar tissue; favorable incorporation is expected in well vascularized graft bed.

Cancellous bone autograft is incorporated into a fracture site in several stages. Revascularization of the graft starts early, within the first several days, and it is completed within two weeks. Huge number of osteoblasts in cancellous autograft directly influences early osteogenesis, and re-modeling rate is three times higher in comparison to the cortical autograft (Frost, 1960) A hematoma is formed at the graft site, followed by an inflammatory response characterized by vascular buds. As vascularization occurs, differentiation of mesenchymal cells into osteogenic cells results in lining of transplanted trabecular bone with osteoblasts. The osteoblasts deposit a seam of osteoid that lines the trabecular cores of dead bone. The osteoid is then mineralized into new host bone. In such way, new bone is laid down at the fracture surface resulting in fusion of the graft with the host bone.

Osteoclastic activity results in resorption of the entrapped cores of necrotic graft. At the same time, hematopoetic marrow elements accumulate within the remodeling graft. This phase of graft incorporation may last for several months.

The graft is completely resorbed and the new host bone remodeled into cortical bone in response to mechanical environment in which it has been places. This phase of graft remodeling takes place within 3 to 6 months following graft implantation.

Radiographic evolution of stabilized fracture in which a cancellous autograft has been placed will reflect biological process occurring. The graft is first observed on the postoperative films as cancellous bone; as the new host bone is laid down, the graft may increase in mineral density, followed by a decrease in density as the necrotic graft is resorbed. Eventually, the cancellous structure is replaced by cortical bone and the medullary canal is reestablished.

Cancellous bone grafting techniques are simple, rapid to perform and enhance the speed of bone healing, in some cases spelling the difference between healing and nonunion.

Cancellos bone, inserted into bone defect shows a tendency to compress and distend, creating subhondral cavities. These cavities can be filled with fine particles of cancellous bone, placed through funnel introduced via minor incision. [34,72] Following previous reduction and stabilization of the vertebral fractures Daniaux (1986) placed cancellous autograft bellow upper surface of the compressed vertebra, using small window made in vertebral pedicle. He claims that after removal of the osteosynthetic material, if bone defect is non filled, bone fusion will not take place.

Complications associated with cancellous bone autografting procedures are very rare, making this procedure one of the most beneficial yet benign procedures in orthopedic praxis. The donor site complication rate is extremely low and includes wound disruption, seroma , fracture of the donor site and seeding of the donor site with bacteria or tumor cells.

Complications at the recipient site involve failure of the graft to stimulate new bone formation and become incorporated in the fracture site. This will result in resorption of the graft and may or may not be clinically evident.

2. CORTICAL AUTOGENOUS GRAFT

Cortical allografts are used where mechanical support is vital (Fig.22) This includes replacement of the segmental bone loss due to peace-or war wound or due to tumor resection where one attempts to preserve the limb. At one stage preferred autogenous bone graft is threatened to become a history, leaving place to methods of distraction osteogenesis, transport of the osseous and vascularized autograft.

Radiographs to the opposite intact bone are made and the length of the bone defect is measured. The cortical graft is most commonly obtained from intact fibula (Fig. 23).

With oscillating saw, distal and proximal fragments are resected, the host and graft surfaces are should be shaped to allow 3600 of cortical contact necessary for the stable fixation of the graft of the host-graft interface. Upon performed stabilization, most often using AO-plate, cancellous bone is harvested from the previously prepared donor site. It is placed around the host graft interfaces to enhance bone formation and ultimately stability of the host-graft interface. Cancellous bone may also be places in the medullar canal of the

Fig. 22.

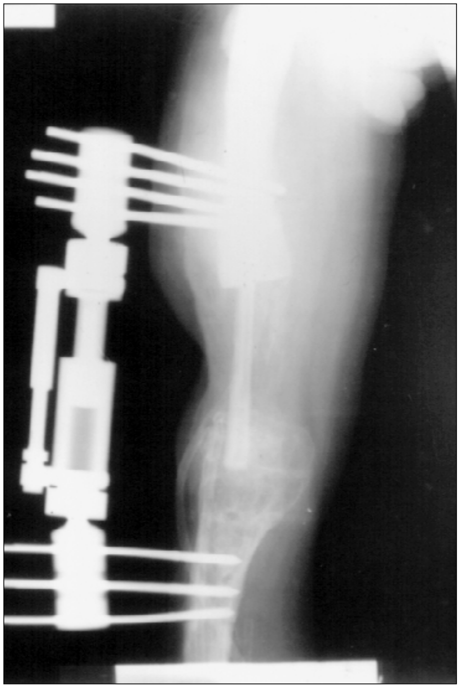


Fig. 23.

graft before the fixation is complete. This technique has been shown to enhance trabecular bone and marrow formation within the medullar canal of the autograft. (74,78,85).

Cortical autografts depend on vascularization, resorption and replacement with host bone for incorporation into healing fracture site. Consolidation of the host- graft interface stabilizes the graft and allows vascular penetration into the cortex leading to the resorption of the graft by osteoclasts followed by new host bone. Resorption of the graft by osteoclasts, followed by replacement with host bone, begins at the host-graft interfaces and moves steadily toward the center of the graft (Fig. 7). This process takes months to years. It may never result in complete remodeling of the bone.

Because of the slow remodeling time, the weakens of the during resorption, and the potential for long-term presence of un-remodeled cortical graft, an advantageous time for plate removal is difficult to determine. Plate removal is recommended at 1 to 3 years following surgery.

Host rejection of the graft is evidenced by sequestration of the donor tissue and formation of a surrounding fibrous connective tissue envelope. Resorbtion of the graft without replacement with host bone also may be an indication of rejection.

Flexible cortical autograft is harvested from the anterior side of tibia. Periosteum is cut longitudinally on two places, 2 - 3 apart. Carefully, with chisel, corticalis, along with periosteum is harvested, within the cut lines and in length necessary for the bone defect. The thickness of the flexible corticall autograft is 2 - 3 mm.

Flexible graft is convenient since it is easily and rapidly modified and attached to the bone. Rapid and adequate vascularization is achieved in due time. Such autograft is used for bridging bone defect along with cortical and cancellous bone autograft. In such combination, flexible cortical autograft is used as an wrapper around cancellous autograft , with ends attachable to the bone.

Consolidation of the host-graft interfaces with bone is radiological observed by 3 to 4 months following surgery. Increased radiolucency of the graft begins at the proximal and distal interfaces and moves progressively toward the center of the graft. Eventually the cortex will regain density as host bone is laid down.

The most common complications include instability of the fracture site and infection.

Infection will result in sequestration of the graft.

Consequently, adherence to the principles of internal fixation and surgical asepsis are essential for the successful use of cortical autografts.

3. CORTICO- CANCELLOUS AUTOGENOUS GRAFT

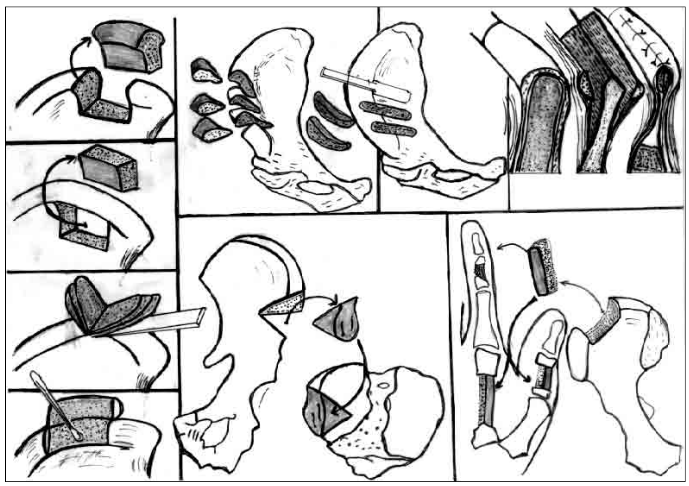
Cortico-cancellous grafts are combination of the two types of bone grafts. They are commonly used on highly osteogenic sites and with technically feasible stabile fixation of fractured fragments. Partially osteogenic site is first, by de-cortication and refreshments of the wound edges, transformed into highly osteogenic site. If closed, medullar canal is opened, with longitudinal drilling. Transplantation with cortico-cancellosu graft on non-osteogenic site may succeed only following reconstructive measures as vascular grafting and infection cure. Only then is non-osteogenic site converted into highly osteogenic site.

In clinical work, often there is a need to use the combination of cancellous and cortical autograft, in order to stimulate formation of the new bone and to achieve mechanical stability. Small cortico-cancellous chips are commonly used for filling in bone defect on stabilized fracture sites. For their power to induce new bone, they bridge defect with a new bone. This technique is used in all fractures associated with bone defects (usually medial) in diaphysis or metaphysis of a long bone , following internal fixation with :AO-plate, external fixator or Kuntscher…If there is zone of comminution of complete defect, bone graft must be inserted into medial part of cortex. Graft is inserted into medial surface of the fracture gap, "packed" into a defect. Graft movements are prevented by suturing muscle over it. Forming small fragments, up to few millimeters, mixing them with blood, a half-solid mass is produced, ideal for filling in defects. If bone grafting is not performed in cases of such fractures, there is a high probability for delayed union, nonunion as well as for the fracture of the osteosynthetic material before osseous consolidation takes place.

Delayed bone union, often the cases after unreamed pins are placed, support the view that reaming of medullar canal is mandatory. Reaming produces osseous dust which acts as an autograft on the fracture site. [23,54,70]

Joint fractures, following their reduction and "lifting", may be strengthen by insertion of anatomically adjusted and designed cortico-cancellous bone autografts. [34,56,70,72] This technique is applicable to proximal humerus, proximal and distal radius, for frmoral condyles, in proximal and distal tibia.

Cortico-cancellous blok, which may be monocortical, bicortical or threecorticaal, are commonly obtained from the rib or the iliac crest bon. These block fill in and bridge bone defect, and also have a stabilizing function. Such graft are placed to bridge defect, attached with their cortical side to cortical bone of host diaphysis , while cancellous side should be well covered by vascularized soft tissue. (Sch.5) Solid and longitudinally divided rib grafts may be used in the same fashion, according to Meeder (1985) Cortical lamellas are placed to lie longitudinally, along axial transfer of load, in order to promote graft re-vascularization. Cortical lamellas may be perforated with 3,2 mm drill, without any significant loss of stability.



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Immediately after re-vascularization , an osteoclastic rsorbtion of the cortex, which provide stability happens, while new bone, formed on the autograft site takes over the function of stability.

Threecortical grafts are commonly used in reconstruction of calcaneus, following Vidal 3 type of fracture, then in corrective osteotomies in one operative procedure…

Factors of most significance are: graft stability, highly osteogenic host site and host-graft contact surfaces . Instability prevents graft vascularization leading to a grafting failure.

3.1. Particled cancellous and cortical graft

Rehn demonstrated that less bone is generated from autogenous cortical grafts than from cancellous bone grafts. This can be explained by the loose structure and considerably greater surface area including vascular connective tissue of cancellous bone. Frost (1960) established that remodeling rate of cancellous bone was three times that of cortical bone. There is a greater number of osteoblastic cells in cancellous bone which has a direct effect on the early phase of osteogenesis. Cancellous bone is relativelly loose-knit due to its trabecular structure and therefore more easily accessible for vascularization. Cancellosu bone graft is already vascularized after seven days whereas the process is considerably delayed for cortical bone grafts.

If optimal repair procedure is chosen (cancellous graft, cotico-cancelous graft, distraction callus or amputation) and if this procedure is carried out within optimal repair time , then, it is up to rationality of surgical technique to provide optimal results, in one or two interventions.

The choice of optimal repair procedure, which will give best results and liest complication rate and patient's discomfort, will depend upon:

a) cause of bone defect - trauma, osteomyelitis, tumor;

b) size of bone defect - up to 3 cm, up to 5 cm or more than 10 cm;

c) bone defect position - metaphysis, diaphysis; upper or lower lim;

d) type of bone defect - partial, segmenta;

In case of defect less than 3 cm, following trauma, cancellous bone grafting is the most simple procedure and thus should be given a priority . [17, 45,49,53,60,70] Recently, more and more authors manage defects even up to 6 cm with bone grafting, according to Phemister, if such defect is of traumatic nature.[70,75]

Vascularized bone graft should be used for bone defects, with 3 to 10 cm in size. If defect results from osteomyelitis, priority should be given to vascularized iliac crest graft, since the rate of successful incorporation is higher and complication rate lower then it is case with fibular vascularized grafts. Transplantation with vascularized iliac crest graft should be elective procedure for partial defects or for defects of half of diaphysis . It is commonly used for mataphyseal and cortical tibial defects up to 10 cm, which are consequence of osteomyelitis , traauma.

The only adequate graft for bridging bone defect of more then 10 cm is vascularized fibular graft, considering the fact that fixation of the iliac crest graft is mechanically insufficient. In adults, fibular autograft may measure even 26 cm. Fibular grafts are commonly used for complete femoral defects, above 4 cm and for tibial diaphyseal defects which measure more than 10 cm.

Segmental transport with callus distraction did not completely replaced conventional methods for bone defects management, but is surely an useful, new procedure for treating bone defects of more than 3 cm. In large defects, conventional methods are less reliable and associated with more problems. Alternative to attempts to bridge defects of long bone is technique of segmental transport with distraction callus, method first described by Ilizarov in 1954. The advantage of this method is no need for autografting procedures, since bone defect is bridged by using the existing, already present bone. Technique of segmental transport transforms zone of bone defect from the partially into highly osteogenic site.

However, segmental transport is not component of primary surgical treatment and thus should be considered only in the second phase, when healing of soft tissues had commenced.

4. ANATOMICAL AREAS OF DONOR SITES AND TECHNIQUE FOR HARVESTING CORTICAL-CANCELLOUS GRAFT

The following areas are most common donor sites for autogenous cancellous and cortico-cancellous bone graft: anterior superior iliac crest and posterior crest of the ilium, greater trochanter of the femur, femoral condyle, proximal tibial metaphysis and medial malleolus of the tibia, olecranon, distal radius.

If possible, autograft should be taken on the same side of the body as the injury, so the intact contralateral limb can function freely and painlessly (Ruter and Lob, 1985).

4.1. Harvesting autogenous graft from iliac bone

Iliac crest is the common donor site for obtaining autgenous bone from the ventral and dorsal side. The other donor sites should be regarded as supplementary areas if, during the surgery, it becomes apparent that only small amount of graft is required for the bone defect or that ilium is not sufficient for the existing bone defect. Posterior iliac crest is optimal sites for obtaining large quantities of the cancellous bone, while anterior iliac crest allows the possibility for harvesting bi- and three-cortical grafts, when structural composition is required.

Anatomic places

The donor sites of pelvis are dictated by its anatomy: The iliac wing faces forward and at the end of the anterior superior iliac spine and obvious prominence runs laterally as a palpable ridge as far as the roof of the acetabulum. In the central part of the wing of the ilium the bone is very tin as it approaches the internal and external cortical laminae. The main reserves of cancellous bone are to be found in this area and in the ventral portion of the ilium where three to four times the amount of bone is found dorsally as ventrally.

The inner side of the ilium is covered and filled out by the iliacus muscle. On the outer side of the ilium are the origins of the iliotibial tract and those of the gluteus minimus and gluteus medius muscles. Lateral cutaneus femoral nerve lies close to the anterior iliac spine (its position varies) which, as a branch of the lumbar plexus supplies skin sensation to the lateral aspect of the tie. In order to protect this nerve during graft harvesting, leg is slighly abducted and flexed in the hip join and small pillow is placed under the ipsilateral buttock to raise it slightly.

Extraction of the graft from the iliac wing :

a) ventral approach

The standard skin incision is made at a distance 1 cm superior to and parallel to the iliac crest so that the post-operative scar will not be on the prominent bone and easily irritated (Ruter and Lob, 1986).

The alternative is to place the incision 2 cm caudally from the iliac crest. This position can easily be determined by pressing on the abdomen with the palm of the hand so that skin is pulled tout over the iliac crest which is the easily visible and palpable. To avoid damage to the lateral femoral cutaneous nerve , the incision should be 2 - 3 cm from the iliac spine. After dividing the subcutaneous tissue the lateral edge of the iliac crest is exposed, and the periosteumeum and the aponeuroses of the trunk and gluteal and the iliotibial tract dissected into intermuscular interval to expose the bone. It is important to maintain a wide periosteumeal border laterally in order to have enough material for subsequent reinsertion. Using the curved periosteumeal elevator the insertions or origins of the abdominal muscles are detached en bloc subperiosteumeally and the medial edge of the ilium exposed. With the blunt elevator or the wide spatula, the iliacus muscle can be detached with the periosteumeum from the concave inner wall of the ilium.

b) dorsal approach:

The standard skin incision starts at the posterior superior iliac spine and extends laterally and cranially to the dorsal iliac crest. An alternative would be to make an incision vertical to the posterior iliac crest in order to avoid the superior cluneal nerves which lie about 5 cm to the lateral side of the posterior superior iliac spine and run from the cranial / medial side in a dorsal / lateral direction. He subcutaneous tissue is divided, the lateral border of the posterior iliac crest exposed and, having cut the periosteumeum and the fasciae, the gleteal muscles are lifted in a single layer subperiosteumally from the outer surface of the posterior iliac wing using the sharp elevator. It is important to avoid damage to the superior gluteal neurovascular bundle which exits from the greater sciatic notch.

4.2. Obtaining cancellous bone graft

There are two procedures for obtaining pure particled cancellous bone wherby the medial cortex remains intact so there that is no loss of functional stability.

A flat, 10 mm chisel is placed on and parallel to the iliac crest and driven into inner table at an obtuse angle. Whit a narrow chisel, two oblique osteotomies are carried out, oblique to the first osteotomy and the medial cortex is opened wide. With the bone curette, the cancellous bone is scooped out from between cortical lamellae. The osteotomy is closed by reinsertion of the window in the cortex on the medial side and by transosseous sutures.

If large quantities of autogenous graft are required, then it is removed from below the lower edge of the iliac crest beginning aitha flat chisel at the inner cortex of the iliac wing and then harvesting all the cancellous bone from the anterioar iliac wing using hollow chisels and bone curettes. The outer table of the ilium must be carefully preserved during this procedure; perforation must be avoided.

The operative field must be thoroughly irrigated and bleeding from the exposed areas of the cancellous bone can be stopped using a haemostypic. No deep vacuum drains are inserted. After insertion of a subcutaneous drain, the wound is closed in layers.

4.3. Obtaining corticocancellous, mono-cortical, bi-cortical and three- cortical autogenous graft from the iliac bone

The continuity of the iliac crest should not be affected in any way by the extraction of bicortical cortico-cancellous graft or bone blocks from the iliac wing.

Incision of the skin, aponeuroses and periosteumeum is performed as for cancellous bone. The periosteumeum on the lateral side, along with attached gluteal muscles, is retracted several centimeters from the outer wall of the pelvis in a caudal direction. The required size of bone block can then be cut from the pelvic wall with an oscillating saw, beginning laterally and just bellow the iliac crest. After harvesting the bicortical cortico-cancellous bone block, the cancellous bone can be scooped out of the bony window as required.

Monocortical cortico-cancellous graft from the iliac bone is most commonly obtained from the outer table. Perforation of the inner table or discontinuity of the pelvic girdle at the level of the greater sciatic notch must be avoided at all costs and the sacroiliac joint must be treated with great care. Bleeding is stopped by application of haemostyptic. Closure of the wound in layers and insertion of subcutaneous vacuum drains.

4.4. Morbidity of the iliac crest following graft harvesting

Potentially significant morbidity is associated with the harvesting autogenous bone graft from the iliac crest. The subcutaneous nature of the anterior iliac crest simplifies its surgical exposure but potentially magnifies the residual deformity. It is more extensive after full -thickness bone harvesting. However, these "secondary" procedures carry with them a c complication rate documented between 3 and 30 %.

Pain at the bone graft donor site is most commonly due to injury of lateral femoral cutaneous nerve. The injures occurs is nerve is overlooked (section, compression) or if nerve is caught in suture during wound closure.

Graft site pain is graded as : significant pain, acceptable pain and minimal pain.

Significant pain was defined as persistent pain that required narcotic analgesics. In such condition, surgery is required as soon as possible.

Acceptable pain was defined as occasional discomfort , required non-narcotic analgesics, and did not interfere with activities of daily living.

Minimal pain was defined as no or occasional discomfort without interference in any activities.

Chronic pain at the donor site was noted to be similar whether an anterior or posterior graft site was used. Majority of authors feel that pain is proportional to dissection and emphasize the importance of meticulous surgical technique. [78,79,89]

Kurz and Scott suggest the trephine curettage technique of harvesting bone graft.

Residual cosmetic deformity was determined by the patients and it consisted of palpable or visible deformity from the antero-superior iliac crest toward the sacroiliac joint along the superior ridge of the crest. This occurred after full-thickness graft was harvested. Amount and the size of the graft can lead to hernia, pelvis instability. These could be ground for the iliac crest reconstruction surgery.

The technique for the anterior iliac crest reconstruction using rib graft was first introduced by Hardy in 1977. The rib sacrificed in thoracotomy or thoraco-abdominal approach is then examined to find the portion that most closely matches the normal pelvic contour. The rib is then carefully cut 1 to 1.5 cm longer then measured iliac defect The tick side of the rib should be facing superiorly because it more closely recreates the thickness of the crest. Once the rib is snugly tapped into place, a high-speed burr is used to decrease the height disparity , corresponding to the subjective complaints of residual deformity. Additionally, if the defect is deeper then the rib, an autograft is placed within a residual defect to prevent potential visceral herniation.

Younger and Chapman (1992) reported 24 successful anterior iliac crest reconstruction among 25 cases. Twenty seven out of 29 patients of Michel and Harris from Houston experienced restoration of pelvic contour with incorporation of resected rib.

Summers and Eisnstein report their disappointment with reconstruction of the anterior iliac crest with acrylic cement while Nasca and Welchel reported their dissatisfaction with allografts from the bone banks compared with rib grafts.

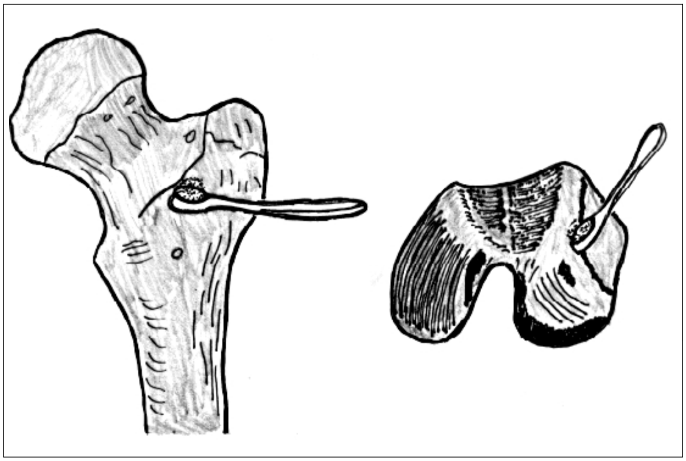
It takes approximately twelve weeks in average for rib graft to incorporate with iliac bone. This process of rib incorporation on the anterior and posterior iliac bone segment is followed by radiography. Clinically, pain diminished or disappeared while correction of deformity occurred.

4.5. Harvesting graft from trochanter major femoris, femoral and tibial condyles, malleoli , olecranon and distal radius

Autogenous cancellous bone suitable for grafting is to be found in the femoral inter-trochanteric region, the femoral condyles, the proximal and distal tibia, the olecranon and the distal radius. These areas are regarded as atypical donor sites. They are reserved for use in those situations in which small amount of graft suddenly becomes necessary during the operation or when the reserves of the anterior and posterior iliac crest have been exhausted.

Femoral condyle - greater trochanter of the femur,

Cortico-cancellous graft should not be taken from these donor sites but rather only small amounts of cancellous bones (Sch..6) When removing bone from the femur, its stability should not be impaired. For this reason, it is recommended that round windows be made with a drill. The cancellous bone is taken through lateral bone window and along the axis of the femoral neck. The bony attachments for iliopsoas or gluteus meius muscles should not be completelly hollowed out because of risk of avulsion fractures. When harvesting cancelloneous bone from the femora condyles, a thickness of at least 2 cm of subhondral bone must remain if collapse of the articulating surface is to be avoided. In both cases the approach is provided by means of lateral incision, greater trochanter or condyle is reached. Application of a



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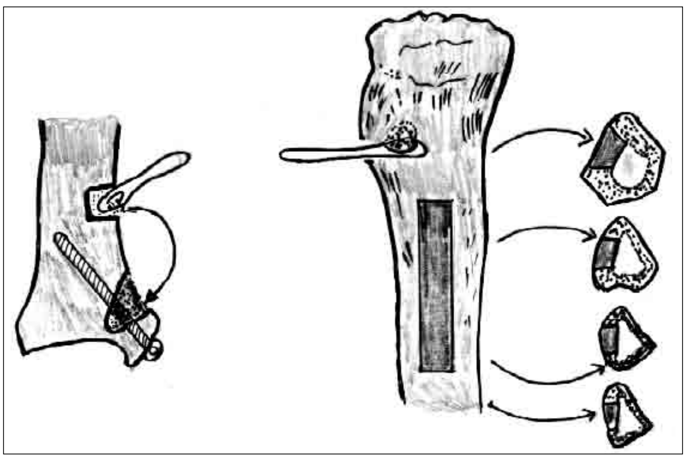
haemostypic in the area of the drill hole and wound closure in layers after insertion of the drain.

Proximal tibial metaphysis, medial malleolus , olecranon and distal radius

Relative little cancelous bone is to be found in these area and extraction of bone may cause instability. An interval of 2 cm to the joint surface must remain in order to retain stability. The bone windows should be small and rounded. If the windows in the cortex are square and rectangular, there is danger of fissure formation, starting at the corners of the corticotomy. Therefore, these donor sites are of secondary importance (Sch.7).



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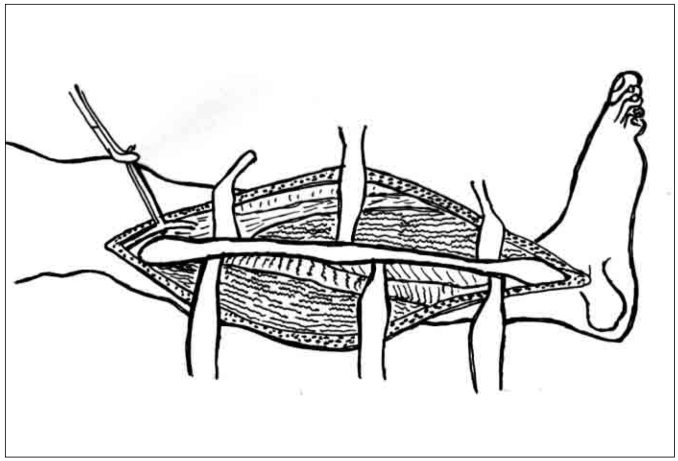
4.6. Obtaining rib autograft

With the patient in the lateral position, this skin is incised over the rib to be resected, preferably the 5th to 10th ribs. These ribs are preferred for anatomical reasons. They approach an angle of 900 close to the costal angle but otherwise they run more or less straight, or curve only slightly towards the bony attachment. The skin and subcutaneous fat are divided then longitudinal division of the periosteum of the rib is performed. After stripping the periosteum down from the edge of the rib, the lower surface is stripped from the periosteum with a Doyne elevator. Rib shears are used to resect the rib; rib sections up to 20 cm in length can be obtained using this technique. Having stopped the bleeding and inserted the drains, the wound is closed in layers and carefully sutured. Harvested autograft is commonly used to bridge the bone defect.



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4.7. Obtaining cortical fibular graft

If the fibula is to be obtained as an isolated graft , an anterolateral skin incision of the lower leg skin is performed, 2-3 cm longer than the actual graft length. (Sch.8). After incision of the fasciae and exposure of the peroneal nerve , the fibula is stripped subperiostally proximally and distally, next to the intramusclular septum, and osteotomies are performed using the oscillatory saw. In children and adolescents attempts should be made to preserve intact proximal and distal fifth of the fibula, in order to prevent secondary complications: valgus deformity and /or instability of the upper ankle.

4.8. Intraoperative treatment of autogenous graft

The biological value of a graft considerably depend on atraumatic surgical extraction and on how much time elapses between the extraction and reinsertion of the graft.

Even today there is no widely accepted approach with regard to graft storage and preservation.

If the graft is kept only for an hour at the room temperature, such extensive alteration takes place that the results of grafting would be similar to these obtained with deep-frozen graft, kept in a bone-bank for several months. [1,2,13] Puranen (1966) reported that if the autogenous graft is kept in physiological saline solution up to two hours, it remains equivalent to the fresh graft. Schweiberer and al. (1981, 1982) maintain that leaving the graft exposed to the air as little as 20 minutes leads to a reduction in the vitality of the graft. They reject preservation of the graft in saline solution and prefer to keep it in blood-soaked compresses . [2,12,14]

Majority of authors recommend that the graft is explanted immediately before transplantation. If it needs to be temporarily stored, then it should be placed in blood or in a moist chamber but not in a physiological saline solution. [70.74]

5. EARLY AUTOGENOUS BONE GRAFTING IN BONE DEFECTS

During the initial period of my active work with war wounds I followed established management protocol. It recommends bone grafting after three months or later, following injury. Performing cancellous bone grafting after two to three months, I faced surgical pitfalls:

1. atypical, altered anatomical approach to the bone defect site;
2. increased chance for the iatrogenic damage to the blood vessels and nerves due to altered anatomy;
3. presence of the atrophic, osteoporotic bone fragments;
4. difficulty in placing internal fixation (AO-plate) due to defect of bone and muscles and associated inactive muscular atrophy.

I had particular interest in bone loss up to 5 cm, resulting from the gunshoot wounds in diaphyses of long bones. In such cases primary surgical treatment of the war wound was performed up to six hours from the moment of the injury.

The visible bone defect remained following the primary wound treatment. This defect did not allow for bone consolidation and loss of circumference, which was over 50 % offered small chance for bone healing. For cases of peace-wounds similar to above described war wounds, Gustillo recommends bone grafting as a treatment of choice. [26,27,29]

In general, healthy covering of soft tissues, along with adequate muscle wrapping around bone defect and absence of clinical and laboratory signs of infection, are necessary conditions for bone grafting. Ideally, these could be achieved within 8 - 12 days following primary surgical treatment.

In war surgery, I indicated early bone grafting in cases where above conditions were met , in cases of diaphyseal fracture caused by gunshot wounds or by pieces of explosive devices.

At hospital admission, prior or following the primary wound management, Tetanus toxoid was administered, and via i.v. line Crystacillin 4 x 5 000 000 and intramuscular Gentamycin 2 x 80 mg.

Stabilization was achieved with external fixation. Such stabilization offers adequate stability, maintains limb length and permits skeletal and musculocutaneous repair.

Diagnosis was based on radiographic examination, verified on operating table. (Fig.24) Often, radiography was not available, due to life threatening conditions or due to lack of films. After primary surgical treatment, size of bone defect would be obvious. The amount of bone loss would decide upon donor place: one or both iliac crest, distal radius, rib…

Laboratory test carried out prior to surgery, in order to rule out infection, were: Sedimentation rate, complete blood picture, differential blood picture. Body temperature is taken daily. In average, wound swab is taken 8th day following primary surgical treatment. Each of these parameters, alone or in conjunction with the other, reveals infection presence.

5.1. Technique for early autogenous bone grafting in war wound

The wound swab is taken eight to ten days following primary wound treatment. If sterile, delayed cancellous bone grafting could be performed. Technique is as follows:

First the operative field for both bone defect as well as donor site are cleaned and prepared. Then the site for cancellous bone graft is prepared. (Fig.25) This includes previous excohleation of the wound, abrasion of the skin followed by rich lavage and consequent removal of dead tissue. Hemostasis is controlled. Place the gauze soaked in saline in the wound and cover with dry gauze.

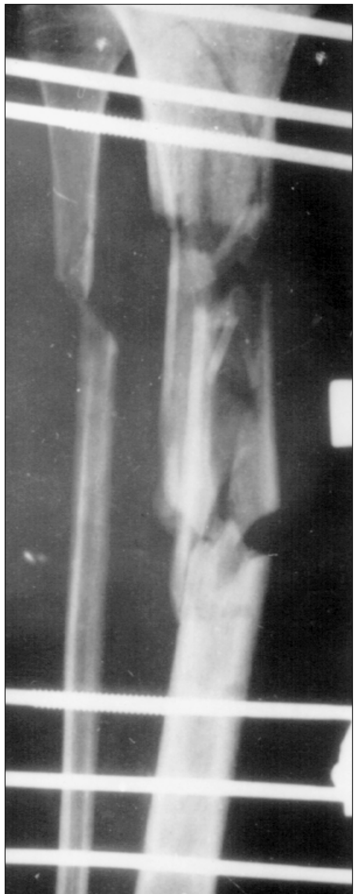

Fig. 24.

From the chosen donor site (decoded by size of bone defect), cancellous autograft, up to 1 cm3 or Phemister cortico-cancellous graft is obtained.

Periosteum is taken when obtaining cortico-cancellous graft, for the osteogenetic and osteinductive potential of osteoblasts, found in cambial layer of the periosteum. Cortico-cancellous possess slighty less osteogenetic potential but it is more convenient for re-vascularization and incorporation in comparison to pure cancellous bone tissue. [2,3]

Large quantities of cortico-cancellous bone are easily obtained. Such graft is resilient to infection as well.

Osteocytes form the autogenous bone graft, which exposed to unfavorable conditions go nonviable, are preserved with such technique. (Fig. 26)

It is necessary to obtain sufficient quantity of the autograft. Extent of the

Fig. 25.

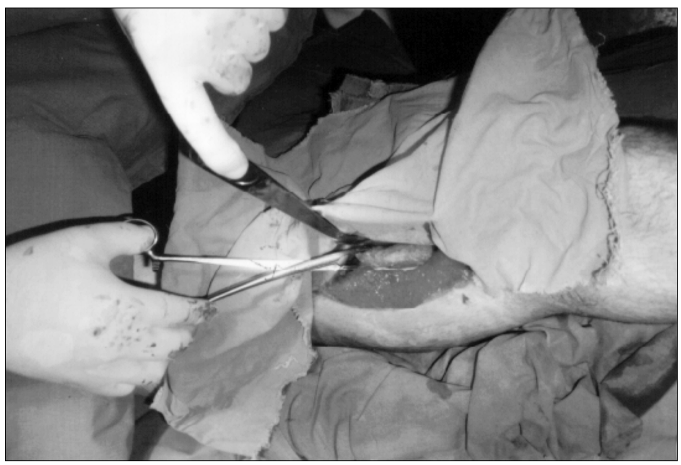

Fig. 26.

bone loss may require both iliac crest for donor sites. Attempts should be made to harvest autograft with meticulous surgical technique, using sharp or hollow chisel, 1 cm wide. Upon harvesting, place the autograft directly from donor site into prepared host bed. After filling the bone defect, the wound i closed in layers.

Bone graft should be well covered by vascularized muscle tissue. If not feasible, healthy skin can be used. Finalizing surgery, donor site is closed in layers.

It is contraindicated to cover bone autograft with Thirsch flap.

Penrose drain is used in donor region, removed the second day.

From the moment of wounding and hospital admission, wide spectrum antibiotics were administered via i.v. line, until sutures are removed.

5.2. Post-operative follow up

Physical therapy starts the first postoperative day in bed. In lower limbs injuries, walking with axillary crutches , depending on stability and size of the bone defect, is allowed from the third postoperative day on. Again, stability and size of the bone defect as well as patient's motivation will determine weight bearing - no weight bearing, touch load or 5 - 10 kilos bearing load.

When operative wound heals, patients are sent for home care. First follow up with radiographic examination is scheduled in six weeks. Patient himself (or family member trained by ward physiotherapist) carries out kinezytherapy or hydro-kinezytherapy (in tub).

Until control radiography, clinical follow-ups after delayed bone grafting should take place every two weeks. Clinical inspect allows to follow progress of soft tissue healing as well as an insight in hygiene around pins of the external fixation. Radiographic follow-up examination verifies clinical signs of the fracture healing.

These parameters determine weight bearing during gait with crutches. Further radiographic follow-up are performed every 30 days; confirming progress in fracture healing, allowing for increase in the weight bearing and range of motion exercises.

Fig. 27. Case from the Fig. 18 and 24, six months following primary bone grafting

SUMMARY OF PRIMARY BONE GRAFTING IN WAR WOUND

Concept of the primary repair and reconstruction of all tissues affected by trauma in the last two decades significantly changed previous conservative treatment approaches.

Propagators and promoters of the early repair procedures in soft tissue injuries (Kleinart - primary surgical management of hand injuries; Janzekovich - early tangentional necretomia in burns, Godina - early microsurgery repair in complex limb injury and Gustillo - early bone grafting in peace time trauma) presented superior functional and esthetic outcomes of an early repair procedure. All authors recognized crucial significant of adequate vascularization in order to achieve better control over postoperative infection and stimulation of wound healing processes.

Therapeutic results in open fractures will primarily depend on treatment of associated soft tissue injuries. Adequate coverage with soft tissue and re-vascularization will provide best conditions for bone graft incorporation and later bone formation. Such conditions are vital for bone grafting. [56,58,60] Bone grafting will offer good result if the osseous host bed is well vascularized, (58) thus bone grafting should not be delayed without reason. Gustillo and associates (1988) suggest bone grafting as soon as threatening infection is under control and process of vascularization commenced. Schwartz and Mears, 1986; Gustillo and collegues 1987; Gordon and Chiu 1988; Peat and Liggins share opininion that in fractures type II and III bone grafting can be performed in the 2nd week following soft tissue coverage with skin graft or local muscle flap.

War wound is more specific, there are field conditions and long term treatment; it requires considering possibilities of more efficient and more rational treatment.

War wound is insufficiently described in world literature; also there no possibility to follow on identical parameter in time and space, making research even more difficult.

Karapetjen and Petrov reported experience on 1361 patients with gunshot wounds in long bones, treated in Angola. In 17 wounded, bone loss was 5 cm and more. Authors followed the stand that internal osteosynthesis in gunshot wounds of long bones can be done under antibiotic protection. Apart from osteosynthesis, authors performed bone grafting with fibular or tibial grafts. All autografting procedures were done following 21 days from injury. Beside bone defect, no other criteria were given for choosing such treatment method. Treatment outcome after 2,5 years: good and satisfactory in 11 patients; poor in 8 patient. Poor results are evident in 3 pseudoarthroses, 4 cases of osteomyelitis and 1 desarticulation of the front foot. For osteomyelitis, fixation material was removed and conservative treatment employed.

Based on available world literature and clinical experience from the recent war, war wound treatment is not focused on infection avoidance and bone consolidation. Multidisciplinary approach attempts at full functional recovery and esthetic of the injured limbs.

Protocol of the primary surgical treatment in war wound is established and fully accepted. Plaster of Paris immobilization and skeletal traction, until the last war commonly used in fractured fragments immobilization, give the floor to external fixation.

Tested in secondary treatment in big sample, used in the last war - rigid osteosynthesis with AIO plate with concomitant bone grafting, proved to be very successful. Basic conditions for utilization of this method are:

- the first phase of treatment completed; neither clinical no laboratory signs of infection present.

Employment of early autogenous bone grafting in war wound with bone defect proved to be possible in the feasible in the primary treatment phase.

Early bone cancellous autografting in war wound can be use if:

a) primary surgical treatment of wound is employed, following standard war wound management protocol ;

b) fractured fragments are stabilized with adequate external fixation;

c) bone defect does not extend 5 cm in length ;

d) neither clinical nor laboratory signs of infection are present;

e) bone graft , following primary delayed or secondary suture, is to be entirely covered with healthy soft tissue (musculocutaneous tissue or full thickness skin);

f) sufficient quantity of bone graft is essential;

g) secondary suture can be be placed with no tension on healthy muscles or healthy skin should cover bone graft;

h) good contact with injured person is established along with adequate and timely physical therapy.

If all above conditions are met; diaphyseal gunshot fracture with bone defect, bridged by autogenous cortico-cancellous bone graft, will reach union during the first phase.

Duration of osseous consolidation in bone loss equals in primary and secondary bone grafting.

Hospital stay of patients who underwent primary bone grafting is cut down for as many days as previously waited for bone grafting in secondary treatment of diaphyseal gunshot fractures (three and more months…).

Early bone grafting (secondary sutures and bone grafting in one operative procedure) eliminates one surgical intervention. Risk of iatrogenic lesions is decreased as well as consumption of surgical material.

Published serial of 18 performed early bone autografting procedures in bone defects resulting from the war wound is not impressive in number. Yet, it can track further investigation in both peace-time and war time trauma. Results, were 15 cases are reported as successful osseous incorporation and 3 cases not successful only justify the need for further research.

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II
DISTRACTION OSTEOGENESIS

1. INTRODUCTION

In the past, children with limb discrepancies exceeding 15 to 18 cm often underwent amputation and prosthetic fitting. Those with limb-length discrepancies exceeding 5 cm were treated with conventional limb-lengthening methods, such as the Wagner technique, associated with a high complications rate and frequent failure to achieve preoperative goals. Those with additional complicating feature of deformity commonly required one or more osteotomies before or after lengthening to achieve axial alignment and limb-length equality.

Thus, it is easy to understand problems arising in bone defect or limb-lengthening treatment if conventional methods when autografts are used.

Significant segmental defects in long bones within partially osteogenic place present serious difficulty to orthopedic surgeon, faced with problem of limb repair and functional recovery. Due to poor local blood supply, bone autografts and heterografts placed by conventional methods of repairs shall hardly lead to successful osseous incorporation. [1,2,16]

From biomechanical stand, most of conventional techniques do no succeed in reconstructing original tubular bone then instead creates hard bony column. [17] Fibula grafts, free or pedicled, always challenge surgical skills and outcome. Not even fibular graft is strong enough to bear imposed load and the final outcome may be nonunion or refractor on interface between original bone and graft or within graft itself. All these techniques are limited by the quantity of graft available and high complication rate.

In orthopedic surgery, there have always been thoughts about limb lengthening and search for the best solution. It started with distraction of ephyseal cartilage or epyphysiodesis, as an attempt in limb discrepancy treatment. Treatment results indicate that upon growth cessation, there is limb discrepancy of varying extent and no solution for it, as well as morbidity on the donor site. [14,17] Standard lengthening ranges from 4 to 7 cm, leaving more severe conditions and dilemma for amputation. [3,4,6]

Bone allografts may transmit unknown antigens, bacteria, viruses or dead foreign bodies , not desirable in infected wounds. Bone graft usually must be reabsorbed and replaced with "creeping substitution" , leaving the structurally vulnerable to fractures for prolonged periods. Bone grafts may never fully incorporate into living bone. [26]

American orthopedic surgeon Codivilla dealt with limb length discrepancy both congenital and acquired with more success. [65] Codvilla presented his own results on orthopedic surgeons meeting in Atlanta, 1905. Following osteotomy, he employed distraction using weight bearing and bed rest, until callus filled in the gap between bone fragments. In 1927, Abbott reports use of Thomas wire as a tool for better axial control and distraction of long bone exposed to distraction osteogenesis using. Bier, in 1923 performs bilateral lengthening of femur in 7 patients with low growth (Achondroplasia) and reports satisfactory results in 6 patients. Introducing own apparatus, Anderson, 1952 gave a significant contribution to distraction osteogenesis.

Wagner, in 1963 modified Anderson's fixator with pins, introducing method consisting of three operative procedures:

1. application of external fixator, ostheotomy and distraction;
2. stabilization of produced limb length with plate while defect is filled by cancellous autograft;
3. plate removal upon osseous consolidation.

Complication rate, up to 40 % (paralyses, osteomyelitis, nonunion, extensive scaring) and maximal lengthening of 8 cm, reveal limitation of this method compared to distraction osteogenesis. [30,33,45,47,49,50,55,63)

Gavrilo Avramovich Ilizarov (1921-1992) from Kurgan, Siberia introduced the method using original transosseal circular external fixation (Fig. 2), method which is today world-wide accepted - distraction osteogenesis. Being the first observer of this process, in one of his patients, Ilizarov has regenerated more than 18 cm of new bone from a single operative intervention, often doubling the baseline bone length.[40,42,44,45,48,50]

This technique allows us to correct deformity, weather it be bony or soft tissue in origin and to equalize limb length in a single operative intervention. The ability to transport and regenerate bone adds the possibility of reconstructing missing bone or replacing pathological tissue with the new bone [1,2,14]

The Ilizarov frame is about 25 % as stiff as uniplaner and biplaner fixators in the axial direction , while maintaining approximately equal stiffness to bending and torsional loads. [7,14] Wire diameter and tension are the most important factors affecting frame stability (Fig. 2a) Other factors influencing frame stiffness are: size, number and location of rings; divergence of transfixing wires; use of olive wires; and distraction or compression loads at the fracture on nonunion site.

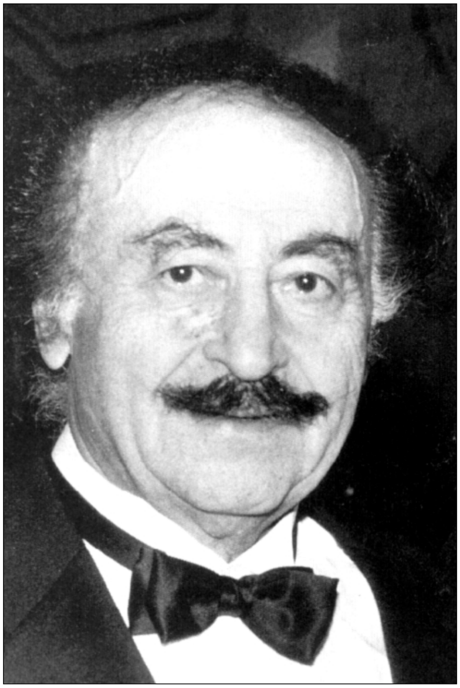


Fig. 1.

Number of rings /frames, arches, distancers and fixator mounting are chosen and applied considering limb circumference on the site foreseen for surgical intervention. [35, 44,48,50] Ring should be at liest 3 cm far from the skin, due to edema and possible skin necrosis. (Fig.3)

Using wires with olive, curved wire and adequate number of rings, contact surface is enlarged and bone sliding on needle is prevented. Proportions of telescopic frames base on the long bone have to equal, for balanced loading and stability. Best stability is achieved with four frames apparatus and following application mode:

a) two basic frames are placed on metaphyseal level, maximally distanced from the core of the problem;

b) two additional frames maximally close to the core of the problem;

c) minimally three pins, with or without

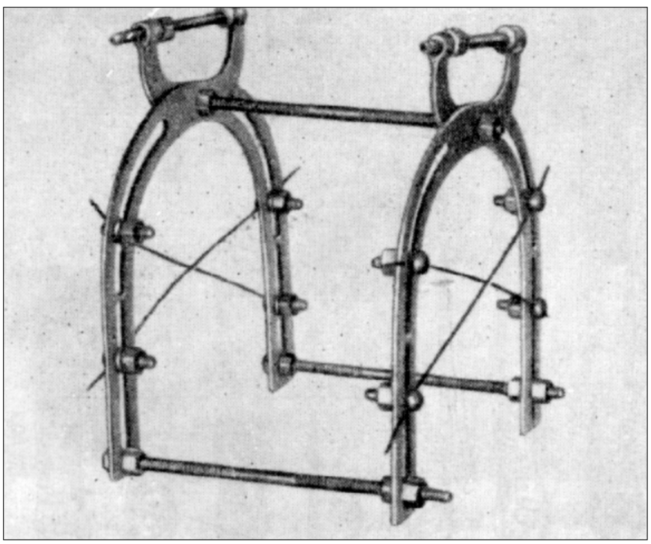


Fig. 2. Fotografija iz Хирургия верхне² конечности книга 1, Медгиз, 1960, first Ilizarov external fixation from 1950.

Fig. 2a.

olives, have to penetrate each bone fragment on different level and in different planes [2,35,37,42,44,50]

Mechanical characteristics of this fixator allow the beneficial effects of axial micromotion without the deleterious effects of torsional and translational shear.[37] The benefits of axial micromotion for fracture healing and bone remodeling, as well as consolidation is achieved with techniques of dynamization and gradual dismantling of fixator. [31,34,47]

Removal of one pin/needle from the frame, every 4 to 5 days, allows gradual weakening of fixation degree. [13,14] Altering fixation degree and increasing function body weight bearing, we preserve simulative axial micro movements required for bone healing. Functional loading stimulates vascularization of the limb, including fractured bone site, preventing osteoporosis to develop. Ilizarov fixator maintains technical control over bone fragments in three planes [1,2,45,47,49] allowing angular and translational corrections as an addition to standard axial distraction.

"Restorative traumatology" is Ilizarov's name for the branch of orthopedic surgery that deals with treatment of trauma residuals, causing new bone formation within a widening distraction gap. [42,44] Skeletal defects can be eliminated without bone grafting. Many types of nonunions can be stimulated to unite by gradual distraction of fragment ends. Malunions can be corrected and posttraumatic limb shortening can be overcome. [2,33,39,49]

Ilizarov fixator and methods Ilizarov introduced , around 600 of them, became widely known and adopted worldwide. Most of Ilizarov methods are extensively used in orthopedic surgery and skeletal traumatology. [57,58,60,62,63]

Fig. 3.

Fig. 4.

Developing this method, Ilizarov proved that varying degree of stability fixation, osteotomy energy are directly related to circulation insufficiency, rate and rhythm of distraction. These are crucial factors for the osteogenesis.

2. DISTRACTION OSTEOGENESIS

Distraction osteogenesis means a method of unlimited new bone production between vascular bone surfaces, separated by the corticotomy. Gradual mechanical distraction allows for the regeneration of the new bone as well as for segmental bone transport via callus distraction (Fig.4) .

The new bone spontaneously bridges the gap and rapidly remodels to a normal macrostructure for the local bone. [38] This method uses local host tissue to regenerate new bone, it offers many potential advantages over bone grafting. Neither autografts nor allografts are required. It converts the area of bone defect from the partially osteogenic place into a highly osteogenic place. [2,4,13]

The primary advantage is regeneration of completely vital bone, capable of bearing load. There are no age limits, as long as the patient carries biological potential for the fracture healing.[2,12,32,45, 49,50]

Standard terminology of distraction osteogenesis is introduced by Ilizarov and as such it is necessary for those performing distraction osteogenesis.

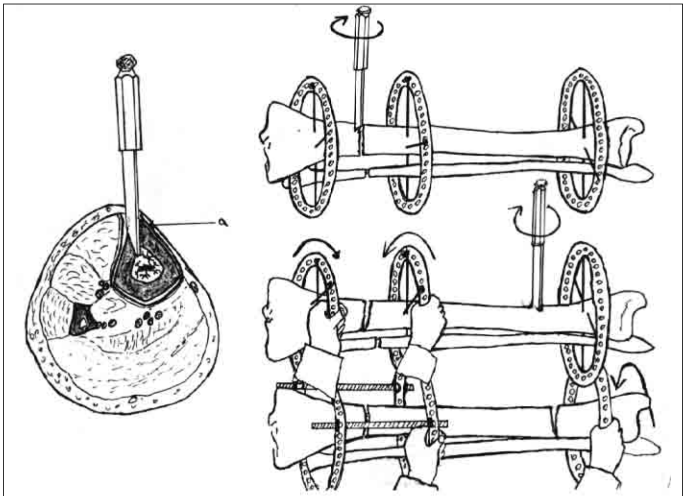
2.1. Corticotomy

Corticotomy is a low-energy osteotomy of the cortex, performed on the problem site - angulation peak, , pathological process and in limb-length discrepancy treatment on the metaphyse-diaphyse interface, for the healing rhythm.

It is crucial phase of this method. It should always be performed in healthy, stabile, non-traumatized area of the soft tissue. Formation of the new bone within intact cover of the soft tissue is essential.

Firstly, rings or pins of the external fixator are placed on preoperatively planned places , then corticotomy is performed.

It is performed by placing tin and 5 mm wide chisel (osteotome), doing small skin incision leading it to the bone, 1 - 1,5 cm longitudinally. Next, cortex is cut, subperiostally, with chisel, first from the medial side, and then from the lateral side also. During this delicate corticotomy procedure, osteotome, toward the bone, should not form an angle more then 100 to 150; simultaneously, rotation with osteotome is performed, for 200 to 300, breaking posteriomedial cortex with it. Meticulous procedure ensures preservation of all structures: skin, muscle, periosteum and endostat. Periostal and medular vascularization is spared and it maintains local blood supply for the periosteum and medullar canal. [40,41,42,44,72] Recent animal studies showed that preservation of the medullar canal is not absolutely necessary. Even if chisel passes through cortical bone and medullar vascular system , with great certainty we expect complete ring of the new bone, which takes longer to form then in preserved medullar vascularization. [1,2,40,41,42] It is essential that formation of the new bone happens within intact area of the soft tissue. [2,3] Corticotomy must be complete in order to allow for uniform distraction. Thus, following corticotomy it is required to check on complete corticotomy. It is sufficient to perform longitudinal distraction with rings, for few millimeters, to check if complete corticotomy is performed. With insufficient experience, it is recommendable to verify corticotomy using radiography - monitor during the actual operation.



Shema 1.

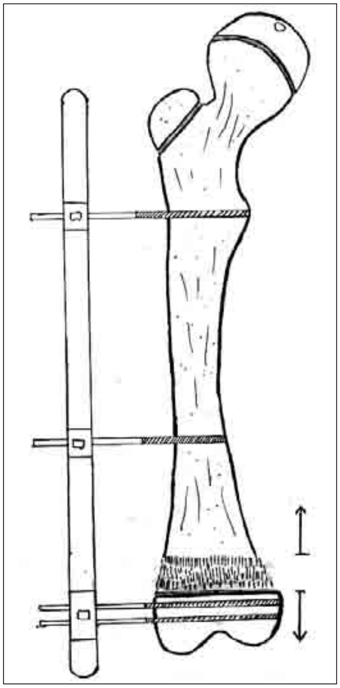
Usually, corticotomy would be decreased when external fixator is completely mounted. With decrease in corticotomy length, local hemorrhage is diminished as well. Osteogenous bridge is ensured, the bridge which should not be compressed for a moment. Injury to nutrient artery or its terminal branch during corticotomy, can indicate local vascular deficiency.

Incision site and osteotomy site should be moderately compressed with bandage on the first postoperative day and osteotomy should rest for 7 days.

2.2. Traction epiphyseolysis

Traction epiphyseolysis is method of epiphysis distraction, used between 13 and 16 years, at the end of the growth period (Risser 4 and 5), in order to lengthen extremities.

It is performed with inserting Kirschner or Steinman pins above and bellow epiphyseal line (Sch. 2). Distraction apparatus is then mounted and only second



Shema 2.

or third day distraction of 1 mm daily shall commence. In average, two weeks following distraction, detachment of the epiphysis will take place and radiography will show apparent widening of the epiphyseal space. As distraction with distraction device continues, during the period of 8 to 14 weeks, limb lengthening up to 12 cm is achieved. [2,4,41,43,56,59]

2.3. Latency

Latency is a period of time after a corticotomy when the initial healing response starts, bridging the cut bone surfaces with a new bone, before initiating distraction. [33,36]

Usually last for seven days. On the seventh days, the total distraction gap is formed and fibrous interzone bridges cut surfaces. Vascular insufficiency at the site of corticotomy may be indicated weather by the lack of normal bleeding or by the excessive bleeding due to the injury of terminal branch of nutritional artery. In these cases, latency can be extended up to 2 weeks. Premature consolidation can occur within 14 days in metaphyseal region and within 21 days in a diaphyseal region. For these reasons, surgeon has to be careful in extending latency. [1,2,47] At the beginning, surgeon should adjust latency in order to enhance osteogenic potential.

2.4. Rate

Rate is the number of millimeters per day at which the bone surfaces are distracted apart. [2,43]

It is shown that most ideal daily distraction is 1 mm. During the process of distraction osteogenesis, it is of help to assess progress of new bone formation. During distraction, adjustment of the rare or rhythm can be necessary and crucial for the optimal osteogenesis. [2,12,58] Standard radiography provides good weekly or biweekly check on the progress of the distraction gap: length, width and alignment.

2.5. Rhythm

Rhythm is number of distraction a day, in equally divided millimeters, resulting in a total rate.

Ilizarov recommended 0,25 mm, per every 6 hours. Optimally, the level of distraction of 1mm in 24 hours is achieved with new serial of unilateral external fixators with pins and frame with implanted batteries, ensuring continuous distraction of 1 mm per day. [4]

Control radiography is usually performed after ten days of distraction. If diastasis bigger then 1 cm is found, it should be reduced by compression to 3 - 5 mm and distraction should cease for three days. Rapid and too extensive distractions, can be followed by pain , edema and limb paresthesia, and all disappear if distraction is diminished.

Standard radiography provides good weekly or biweekly check on the progress of the distraction gap: length, width and alignment. Usually by the third week of distraction, if radiography is correct, new bone mineral appears as fuzzy, radiodense columns extending from both cut surfaces toward center. The absence of new radiodensity by the four weeks of distraction is a worrying signal for the surgeon.

Ultrasonic examination is sensitive to mineral depositions before appearance on plain radiographs. Vascular channels may mimic new microcolumns of the bone. Occasionally, the distraction gap appears empty by ultrasound, indication a cystic cavity. In this rare instances, distraction should cease. The gap should be gradually closed until the corticotomy surfaces engage for a repeat latency before re-distraction.

The hystologic zones of distraction osteogenesis create a predictable pattern of mineralization that can actually, qualitatively and quantitatively, be measured with CT. Presence of the uniform sequence by CT allows visualization of the fibrous interzone. Any area with within the distraction gap that is less than 60 % of the density of the normal side is at increased risk of angulation, fracture.

Rhythm of distraction is adjusted according to clinical finding and radiography results. With further distraction, radioghraphy is usually taken once a month. When radiography is performed with metal rod , apart from the achieved length , quality of regenerated bone is verified.

If this radiolucent zone forms an hourglass appearance wider then 1 cm, then it certainly leads to prolonged consolidation and fibrous interzone needs to be expanded.

Decreas of the radiolucent zone bellow 0,5 cm leads to premature healing and prevents to achieve planned lengthening. Fibrous interzone narrows and primary mineralized front expands. In such case, distraction rhythm should be accelerated.

In attempts to lengthen the extremity more ten 7 cm, break of or 2 days should be made after the month of distraction. Further on, breaks of 1 to 2 days should be done more , following each 10 - 12 days of distraction. When adequate length is achieved, apparatus is fixated, while tension of the wires is maintained by 0,5 thread tensioning on all telescopic rings, every seven days.

2.6. Transformation osteogenesis

Transformation osteogenesis means the conversion of the non-osseous interpositions into normal bone by combined compression and distraction forces.

Often, there is fibrocartilare or synovial cavities in pseudoarthroses. Sometimes, there is a need to augment transformation osteogenesis by nearby corticotomy.

2.7. Bone transportation

Bone transportation means the regeneration of intercalary bone defects by combined distraction and transformation osteogenesis.

Bone transport is an unique application of the biology where large intercallary defects in bone from trauma, infection or tumor can be regenerated by simultaneous distraction osteogenesis and transport of a live segment of bone across the defect. As in the case of the atrophic nonunion, this multifocal treatment involves distraction and eventual compression of the transported bone segment top the other bone segment. Transport can be carried out proximally, distally or even transversely.

In course of segmental transportation, one of parts of the long bone, above or bellow zone of defect , is cut with chisel. Cut is made on the level where soft tissues are not damaged. In order to mobilize diaphyseal bone segment (Fig. 5) This segment is transported into bone defect , 1 mm in length a day, by adequate traction produced by mechanism of the external fixation. On the spot of performed corticotomy in healthy soft tissue, with gradual lengthening by traction, the extent of bone defect decreases. Woven bone is formed in the distraction zone, as a response to tension. With time, through mineralization and increased mechanical load, woven bone transforms into lamellar bone. When bone defect is completely bridged, bone segment replaces previous bone defect and bone union is ensured by compressive forces between bone fragment and bone segment. Mechanical and biological efficiency of this method result from the fact that transection of bone diaphysis and segment move-

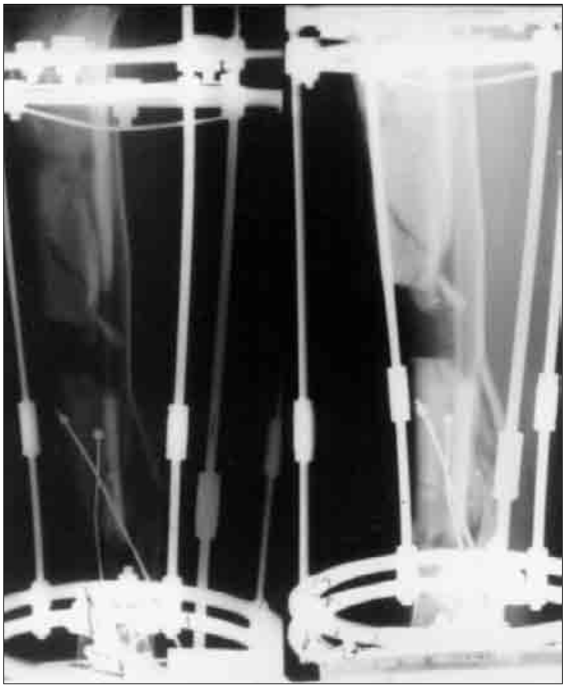


Fig. 5.

ment create tension and induce hypervascularization in the given zone. These two effects seem to be fundamental basis for the new bone formation. Segmental transport is not part of the primary surgical management and as such, it is considered only in the second phase of treatment, following soft tissue healing. (1,3,41,43,47) In acute trauma, the extent of the bone loss and soft tissue damage, become apparent only after primary surgical treatment and bone fragment stabilization. With soft tissue healing and with re-assembling of the placed external fixator or mounting the other, which will then allow for bone segmental transport and treatment until the cure.

The transported segment is usually the entire cross section of bone but can be partial fragment to fill a partial gap, such as in cavitary osteomyelitis .Each cut bone surface has a blood supply and distraction is carried out at the proper rate and rhythm by stable external fixation following an appropriate latency, distraction osteogenesis should produce new bone that rapidly remodels to normal.

Fig. 6.

Mechanical and biological efficacy of this method result from the fact that transection of bone diaphysis and segment movement create tension and induce hypervascularization in the given zone. These are basic preconditions for the formation of new bone.

Corticotomy should always be performend in non-traumatized soft tissue, in the proximal or distal part of the long bone.

Segmental transport by callus distraction did not replace conventional methods of bone loss treatment yet. However, it is useful procedure in management of bone loss extending over 3 cm in length. In extensive defects, conventional methods are less reliable and associated with more problems.

2.8. Healing index

Healing index means the number of months from operation to full, unaided weight-bearing for each centimeter of new bone length.

Distraction osteogenesis allows regeneration of completely vital bone, capable of bearing, at pace of approximately 1 cm in length a month in children and two months in adults.

Complete re-building of the bone marrow and formation of the medullar canal, takes place in children after 6 to 8 months, and in adult, in 10 - 12 months. Process of bone remodeling does not finish with cessation of distraction process. Time needed for the new bone to mature is usually two to three times longer then the time necessary for the segmental transportation. (23,41,47)

Decision on external fixator dismantling and schedule for pins and wires removal is brought by orthopedic surgeon. Decision is based on radiography and clinical evaluation.

Radiographic attributes (Fig. 4, 6, 12, 15) of the newly formed bone, capable of loading are :

1) density of regenerate obtained by distraction osteogenesis should be the same as density and structure of the bone producing regenerate;

2) regenerate trabecules are parallel and follow direction of distraction forces;

3) regenerate diameter should match bone diameter;

4) continuity of the cortical plates achieved, regardless their thickness, continuity matters only.

Clinical signs at the end of fixation period: full, painless weight bearing with function is achieved. This is possible if physical therapy is carried out 1,5 to 3 months prior to removal of external fixator. Newly formed bone is used to graded weight bearing : from the touch weight bearing to the full weight bearing.

When radiological and clinical signs are clear, destabilization is gradually performed. It commences with reduction of distraction forces 0,25 mm once or twice a day, until neutral position. Such method decreases rigidity and increases elasticity of the micromotion in the area where new bone growths into a host bone. Pins and needles are alos gradually removed; 1 pin or 1 wire each 5 - 7 days, close to the newly formed bone. Such procedure maintains and increases pressure, accelerates reparative regeneration and corticalization of the regenerate, along with holding others on distance from the newly formed bone. Fixator is dis-assembled , folowing prevoiss check on the new bone stability , no great force is used. Fixator is removed in out-patient department.

In this way, fractures are prevented, as well as potential lessening of achieved length, angulation …In the period following removal of external fixator, gait with axillar crutches with graded weight bearing is prescribed. First radiographic follow up is scheduled in a months time and full weight bearing is allowed in 1,5 to 2,5 months following removal of external fixator.

Treatment of such patients is individual for each person, as every case is very specific.

3. HYSTOLOGY OF DISTRACTION OSTEOGENESIS

The initial latency period appears to be no different than routine fracture healing. [12,14] Fibrin-enclosed hematoma and inflammatory cell infiltration fill the gap at the corticotomy site.

During the period of latency, which lasts for seven days, mesenchymal cells begin to organize a bridge of collagen and immature vascular sinusoids. [6,8,12] Fibrovascular bridge organize itself parallel to the direction of distraction. The collagen network becomes more dense and less vascular, almost assembling tendon. Vascular channels remain located in the intramedullary region, closely approximated to the cut surfaces of the corticotomy segments, not crossing to the fibrous interzone. [1,2,40,41,43] Spindle-shaped cells resembling fibroblasts are loosely interspersed between collagen bundles bridging two cut bone surfaces, including periosteum, cortext and bone destroyed by corticotomy in medullar canal. There are neither osteoblasts nor osteoids.

During the first week of distraction, this central zone of relatively avascular fibrous tissue bridges the entire 6-to7-mm gap, produced after corticotomy, called fibrous interzone. [2,3,45,46,47] As distraction proceeds, the central fibrous zone remains as an radiolucent zone, 4 to 8 mm wide, while more and more bone is added from each end of corticomy bone. If there are mineral radiodense columns of the new bone from both surfaces toward the center and fibrous interzone narrows, the distraction rate should be accelerated. If the new bone forms an hourglass appearance and the fibrous interzone is widening, the distraction rate should be decelerated.

During the second week of distraction, osteoblastic cells appear in clusters adjacent to vascular sinuses on either side of the fibrous interzone. Collagen bundles become fused with a matrix resembling osteoid. [40,41,43,44) By the end of the second week collagen begins to mineralize. [5,7,8] These early bone spicules, called the **primary mineralization front**, extend from each corticotomy surface toward the central fibrous interzone like stalactites and stalagmites. This osteogenic process is seen uniformly covering the entire cross section of the cut bone, including periosteum, cortex and medullary spongiosa.[(8,9,40,41,43,44)]

From the third week on, this process continues, with the fibrous interzone undulating across the center at an average thickness of 6mm and the distraction gap increases. The bridge is formed by the elongation of the new bone spicules. [1,2,3,41,43,47] The tips of the spicules begin at a diameter of about 7 to 10 microns, while expanding to diameters of up to 150 microns toward each corticotomy surface. Each microcolumn of new bone is is surrounded by large thin-walled sinusoides. [1,2,44,47] This zone is called microcolumn formation. [2,4,40,41] At the conclusion of distraction, the fibrous zone ossifies, creating a new zone of microcolumn formation and completely bridging the gap.

4. PHYSIOLOGY OF DISTRACTION OSTEOGENESIS

Probably the most important physiological factors in successful distraction osteogenesis are the regional and local blood supply. Each column of the new bone is completely surrounded by large vascular sinusoids. The appearance of clusters of osteoblasts at the tip of each column is in close proximity to these sinusoides since these vessels parallels the bone column and distraction force. Still, very few actual vessels cross the fibrous interzone, which remains relatively avascular.

Stability of bone fragments following corticotomy in all directions, except in micro movements, ensures optimal conditions for the distraction osteogenesis.

5. PATOPHYSIOLOGY OF DISTRACTION OSTEOGENESIS

Certain conditions that reliably lead to poor osteogenesis are excessive rate, sporadic rhythm, initial diastasis, frame or bone-fixator instability, poor regional or local blood supply, traumatic corticotomy…

It is easy to postulate that an initial traumatic corticotomy and diastasis would inhibit the formation of a primary fibrovascular bridge.

Instability of bone fragments and their macromotion will disrupt formation of the fibrous interzone, microcolum formation and delicate vascular channels.

The importance of rate and rhythm may well involve the biosynthetic pathways on the cellular level of protein synthesis and mitosis.

Peripheral vascular disease may limit regional vascularity and a traumatic corticotomy can severely disturb the local flow.

Biopsies from the sites of failed osteogenesis revel ischemic,[2] atrophic fibrous tissue when the cut bone surface is devoid of osteocytes and red cells.[2,4, 41]

If the bone ends are initially separated more than 1 cm or are distracted too quickly and thus islands of cartilage proliferate in the gap, [1,3,45,47] it will result in destabilization of the newly formed bone. It will further lead to breakdown of the microcolumns and subsequent replacement with fibrocartilaginous nonunion. [4,6,42,75]

6. MODE OF APPLICATION FOR PINS AND WIRES OF THE EXTERNAL FIXATOR

In order to perform standard procedure in distraction osteogenesis in bone defect treatment , it is necessary to adequately insert pins or wires through skin, muscles and bone. During insertion and application, one should bear in mind great mobility of sift tissue and skin, their permanent changes in position during various movements in joints. Ignorance and inadequate insertion of pins or wires can lead to development of dezmogenous joint contractures . Increasing ROM in such joint is difficult, followed by extreme pain and pins and wires cut the skin causing local infection. Unremitting painful sensations during each movement, result in immobility, then in no weight bearing and consequently to delayed bone consolidation , algodystropy…

6.1. Application of the pin

In order to achieve adequate stability of bone fragments with external fixator which uses pins, it is necessary to ensure stabile, solid contact between the bone, the pin and the frame of external fixator. In other words, to create technical conditions needed for distraction osteogenesis.

The application of an external fixator with pins begins with 1 cm skin incision. When smaller incision is applied, it causes twisting and necrosis of the skin, squeezing and additional necrosis of muscles, impair the continuous lymph filtration, decreases skin mobility / stretch, thus preventing the full function of extremities, leading to joint contractures.

An incision bigger then 1 cm leaves the wound open to aerogenic infection.

After the incision, provide the access to the bone, along the muscle fibres, between muscle groups with a blunt instrument. A drill sleeve, with a trocar inside, is inserted into spared space. Leaned on the bone, strike trocar with a hammer to mark the place where bone will be drilled. This prevents drill sliding and possible maceration of the surrounding soft tissue.

A drill should be sharp, with about 700 rotations per minute (optimal). (34,42); making pauses to allow drill to cool. A great number of rotations of a blunt drill raises temperature to 140 0 C at the drilling site. Consequently, at 0,5 mm distance the bone devitalizes, via aseptic necrosis and osteolysis. There is also an increased risk of pins loosening and infection (Mathews, Hirsch, Chao, 1990).

Pin loosening and associate instability when weight bearing, can cause unequal loading inside the pin whole and instability of the pin-bone spot. Continuous micromovements result in pin loosening, or instability on the fracture site and produce conditions for fracture bending whenever pin is loaded. To prevent this instability, Ardnel and al., 1998, accomplished well controlled extent of the radial loading by small disproportion in pin whole and pin size. Experimentally, they proved that optimal disproportion is 0,1 to 0,2 mm , while disproportion of 0,3 mm results is mechanical damage and leads to later micromovements and bone resorbtion. [2,26,27]

In day to day work I use drill bit which is 2 mm thinner than the pin.

The size of the contact surface between the pin and the bone is increased by inserting pin of greater diameter (5,6,7 mm), on the largest bone crosscut diameter (mataphysis) and through the middle of the bone. Pin threads increase the contact surface and prevent bone sliding, enhancing stability of bone fragments.

When inserting thin pins subcortically, with no shreds, through diaphysis, contact surface between pin and bone and decreased.

There are pins with 3,5 to 7 mm in diameter, 50 to 250 mm in length, shredded or non-shredded. Commonly used today are short-shredded 4,5 mm for cortical bone insertion and long-shredded for the cancellous bone insertion.

Well known and most often used is Schanz's pin, various in length, which on the top or in the middle has a shred, ensuring better stability and bone-pin contact. Steinman's pin , compared to Schanz's has no shred. De Bastiani, proposes strong, cones shredded pin for application on his external fixator. Such pins facilitate assembling and ensure greater pin-bone stability, an easier dismantling and lessen infection rate. Pin with shreds are extensively used when transport of the bone from to another site is required- "lifting" or when preventing fragments from moving away.

Recently, there is new generation of pins allowing for the radial loading, with small disproportion between pin whole and pin diameter. Advances in production technology and material, from the iron to titanium, questions Schanz's pins as well. With these new pins, which are still widely used, concept of external fixation could gain additional advantages.

External fixator without pins is a clasp which fixates the bone with support of its two sharp tips and with no penetration into medullar cavity. (Fig. 7) There is no communication between medullar cavity and external environment.

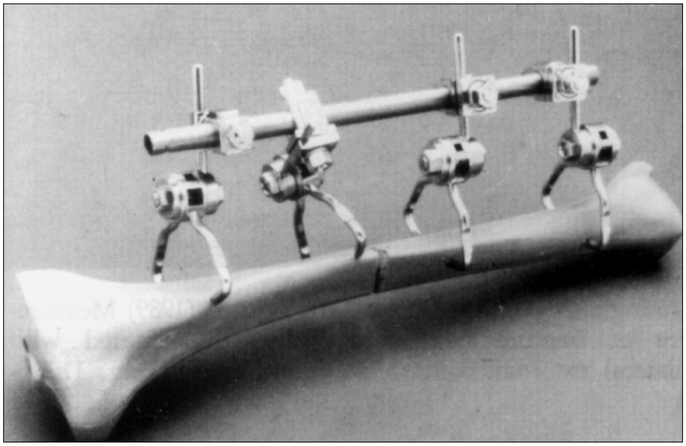


Fig. 7 - taken from AO/ASIF Scientific Supplement, Volume 23 - Supplement 2, INJURY, 3 31, 1992.

Such design prevents that pin infection reaches medullar cavity and local circular vascularization remains intact. This system of fixator without pins consists of different clasps, connecting one next to other and adapted by long clasps along carbon tube. Clasps are connected to the tube as reduction tongs. This fixator provides lesser stability then unilateral fixator with pins and can not be used for prolonged period of time. However, it is convenient for achieving temporary stability of bone fragments in primary surgery, while conditions for the definitive management in secondary surgical intervention are met. It is suitable for ambulance.

When inserting pin, the plane of the pin should be parallel to the axis of the nearby joint. At the same time biomechanical principles and anatomical structure of the pin application site should be considered. Exemption of these is only tolerated in the following cases:

1. when apparatus is foreseen for the longer period of time;

2. when greater force should be overcome; prevention of valgus, antecurvatum or extensive bone defects…

Pin should not be inserted through tendon, muscle , joint bursa or in nerve vicinity. Pin insertion on such sites usually causes problems.

6.2. Pin infection

The term pin infection is not well defined in literature. In 1983. Gordon introduced terms "minor" and "major" infection with onset around pins. The major infection means redness of the skin around pins, edema, pain and an increased secretion around pins,. All other pin infections are seen as minor, with spontaneous resolution or disappearing after proper pin care. Major infection often requires hospital admission, administration of antibiotics and when associated with purulent secretion even an urgent pin removal or pin replacement.

Infections (minor and major) around pin are common, and according to different authors, occur in 0 to 50 % of cases. Green and Riplen, in 1984, indicate residence of the chronic osteomyelitis associated with external fixation with pins in 0 to 4 %. All pins are placed in cortex ; none into a cancellous bone. (2,4,17,23, 28,41,46, 68)

Number of pins should be minimal, still providing adequate stability in bending and axial arm, while axial loading stimulates consolidation of distraction osteogenesis. In trauma management, accurate reduction and stabile fixation must be ensured until the fracture union is accomplished.

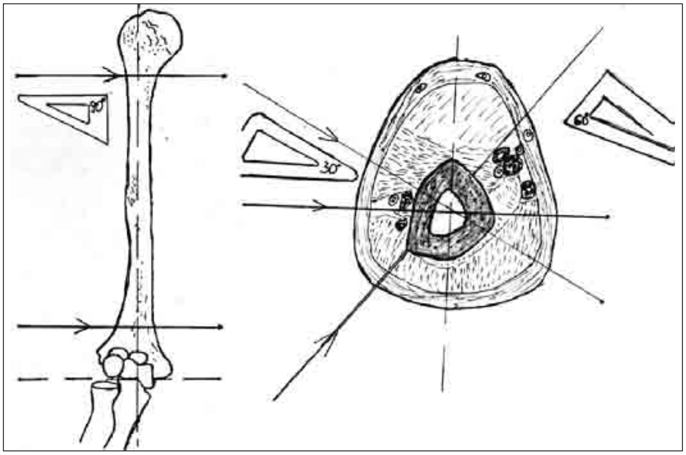
Some authors prefer unilateral fixators with pins to fixators with half-rings, rings with Kirschner wires, advantages being an easy assembling, diminished risk of neurovascular injuries, minimal maceration of musculocutaneous tissue, an easy dismantling, an easy radiographic follow up , better tolerance for patients with regard to comfort and hygiene. Most preferred such fixator is Ortofix, for its technical, physiological and biomechanical attributes. Ortofix is used for trauma, in osteotomy fixation of joint distraction and for limb lengthening.

Frame which is placed on pins should be 2 cm distanced from the skin due to edema, and pin toilette.

6.3. Application of wires

Good contact between bone and wire surface, which ensures adequate stability of bone fragments when performing distraction osteogenesis, is a key factor for success.

Good contact is established, firstly by applying Kirscner wires perpendicularly to diaphysis in horizontal plane; percutaneously and parallel to the axis of the nearby joint. (Sch. 3) . Crossing in two planes, horizonatl and fronts, is possible in distal humerus and femur. Optimal stability is accomplished with reciprocal crossing of inserted wires at angle of 60 0; the angle less then 30 0 does not ensure adequate stability of fragments; while angle of more then 60 0 carries a risk of damage to internal structures. Depending of fixator model, wires can be



Shema 3.

parallel, transossealy placed. Stability in all three planes is less in comparison to insertion of mutually crossing wires.

Wires insertion on the biggest bone diameter (metaphysis and bone middle, not on diaphysis and subcortically) contact pressure is evenly distributed to greater bone surface. Wires insertion requires good knowledge of topographic anatomy of the limb which will determine direction and angle of wire crossing. Attempts should be made not to insert wire through tendon, muscle or joint bursa. Iatrogenic complications of blood vessel or nerve are serious complication.

Wire insertion through soft tissue is done with stab not with drilling. It avoids spinning of fascia, muscles or tendon around wire. Insertion of the wire next to the nerve and irritation respond, calls for the site changing. Reaching the bone with tip of Kirschner wire, anterior and posterior bone edges are determined; tip id placed in the middle and drilled through the bone. Stop drilling frequently to allow wire tip to cool and to avoid tissues burning. High temperature widens tract for Kirscher wire and results in unstable contact between the wire and osseous tissue, a key for stability. Wire direction maintained with gauze soaked in saline, alcohol or iodine solution. Upon penetrating the bone, pass the wire through soft tissues with hammer strokes. After inserting wires, we place rubber bottle-stoppers to hold gauze pads around the wires and allow hygiene later on.

High mobility of the skin and soft tissues, as well as change of their position during joint motion, require limb to be placed in adequate position, in order to preserve joint motion.

A simple test on distal lower arm can illustrate how important it is to change joint position during Kirschner wire insertion. Fixing skin on the dorsal side of lower arm, with hand in maximal dorsal flexion, it is impossible to do full palmar flexion of the hand. Similar tests can be done for each joint. It also proves that holding a joint in one position during Kirschner wires insertion inevitable leads to dezmogenous joint contracture. Treatment is uncertain, followed by painful sensations caused by wires cutting the skin and producing a local infection.

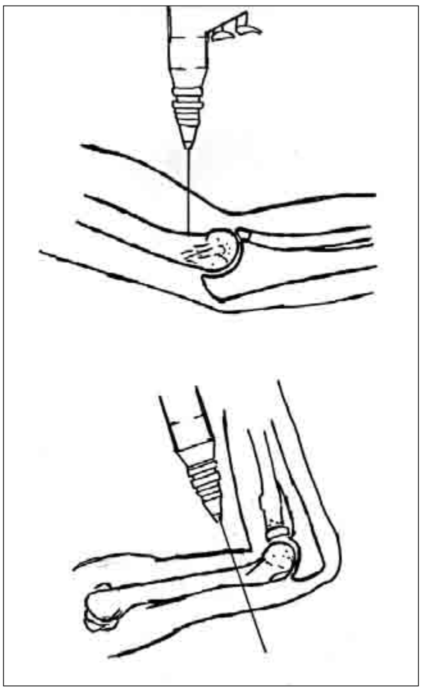
For these reason is necessary, when inserting wires, to displace soft tissues or to change joint position so would movements in the joint be painless even after mounting the frame of external fixator.

6.3.1. Application of fixator with wires on upper arm

Method of distraction osteogenesis is indicated when an osseous consolidation is needed, where attempts are made to achieve proportionality, functionality and esthetic accord with the other forearm; in humerus pseudoarthorses, in bone defects with forearm abbreviation above 3 cm, in congenital or in acquired deformities in one or both forearms.

Patient is supine , operative field allow free access to the shoulder and the elbow, or full access to proximal and distal metaphysis of humerus. Upper arm is abducted for 800. Kirschner wires, crossing at angle of 250 to 450 are inserted on horizontal plane, perpendicularly through proximal metaphysis. When inserting wires, taking care of muscles and skin function and changing shoulder position, painless movements will be ensured.

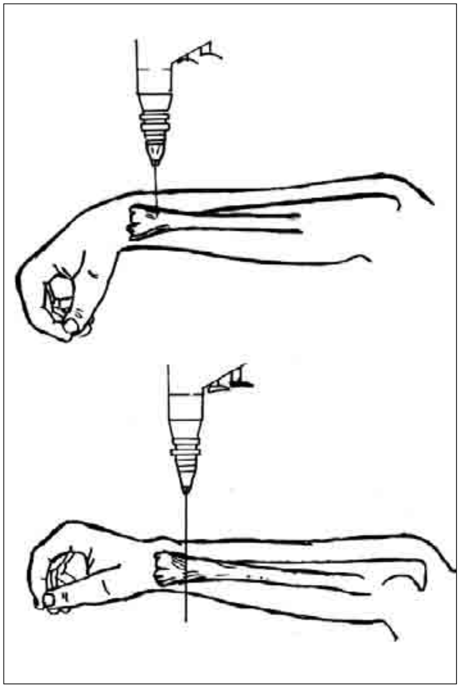
Positioning the elbow in extension, Kirschner wire is inserted into distal humeral metaphysis, perpendicularly to humerus (Sch. 4). Mutual crossing of Kirschner wire in horizontal plane is 250 to 300, in horizontal plane up to 500; fossa olecranii and processuss coronoideus should be left free. When wire passes through skin and muscles from the ventral side, from the position of extension, elbow is brought into 900 of flexion. In this position, wire passes through muscles, skin, dorsal side of the upper arm. Such insertion techniques provides for full shoulder



Shema 4.

mobility and elbow, along with stabile fixation.

The size of the bone defect or shortening may require two corticiotomies. In such case, elastic spacial stability is accomplished by placement of more rings and by insertion of more wires in the frontal plane. If necessary, Kirschner wires may be inserted through ulnar acromion.



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6.3.2. Application of fixator with wires on forearm

Using method of distraction osteogenesi in forearm, due to a mass, anatomical and functional importance, corticotomy is performed in:

- proximal part of metaphysis of ulna;
- distal in metaphysis of radius.

Method is commonly used in orthopedic surgery for congenital hypoplastic and aplastic deformities of forearm and hand, in enhondral ossification impairments, traumatic injures, pseudoarthroses, mal-unions or in bone defects in one or both bones. Abbreviation of one of bones (ulna or radius) for more then 2 cm is followed by obvious deformity (radial or ulnar) and with hand fixation. Forearm abbreviation for more than 3 cm is apparent esthetic deficiency; resulting in permanent angulation of thoracic spine, further leading to scoliosis and to hypotrophy of shoulder girdle.

Stabilization of proximal metaphysis of forearm is accomplished by inssering Kirsschner wires perpendicular to bone axis, with wires crossing at 25º to 30º in horizontal plane. Greater crossing angle, 30º to 50º, is achieved in frontal plane of ulnar metaphysis. If desired outcome requires, one wire can pass through both bones. Distal metaphysis is stabilized by inserting Kirschner wires perpendicularly to bone axis and by wires crossing at angle of 25º to 40º in horizontal plane. Angle may increase if one of wires passes through both bones. To allow full range of palmar and dorsal hand flexion, it is necessary to position the hand in maximal palmar flexion while Kirschner wires are inserted from dorsal side (Sch. 5). While Kirschner wire comes out to palmar side, hand should be brought into dorsal flexion prior to wire passage though soft tissues and skin of distal lower arm. Wires and tensioned and fixated to half rings or rings with three to four telescopic frames.

To accomplish desirable results by distraction osteogenesis of both bones, proximal corticotomy of ulna and distal corticotomy of radius are performed.

In case of one or both bone abbreviation deformity, corticotomy is performed on the angulation peak.

If relations in both joint are within physiological values, they are then preserved with Kirchner wire passing through both bones.

Distraction osteogenesis of one bone, for bone loss compensation, or both bones, with different sizes of bone defects, is accomplished by distal mounting of one or two half-rings of external fixator with wires, independently. With such mounting technique, independent compensation of bone loss via distraction osteogenesis can be achieved.

6.3.3. Application of fixator with wires on upper leg

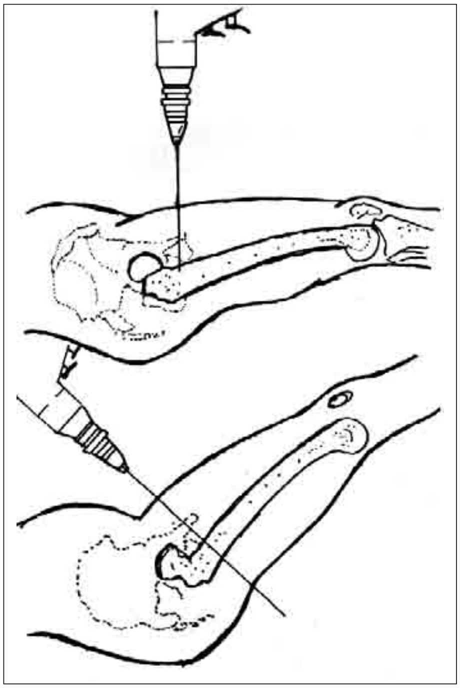
Operative filed should allow for free access to pelvis and knee. Upon anatomical orientation, than palpation and marking a. femoralis, skin is "tensioned" distally, hip is extended (Sch. 6) and first wire is inserted from forward to backwards in, through femoral metaphysis in intratrochanteric region. When wire passes from forward to backward through skin, muscle and bone, then hip is flexed and wire passes through distal tight - bone, muscle and skin. Second wire is usually inserted from backward to onwards, crossed at angle of 25º to 30º in horizontal plane. Commonly, three wires are inserted, at liest one with olive and none close than1 cm to femoral artery. More stabile fixation can be achieved inserting two wires in horizontal plane, one wire in sagital plane, on the frame mounted few centimeter bellow proximal ring. This ring is with extensions connected with other ring or uses telescopic frame which unites distal rings.

Inserting Kirscner wire through distal femoral metaphysis, knee is flexed to 90º and needle is inserted through skin, muscle and bone. When wire passes through the bone , the knee is extended and Kirschner wire passes through muscle and skin. (Sch. 7). Two Kirschner wires, crossing at 500 to 600 in horizontal plane, are inserted, tensioned and fixated to the ring.

More stabile fixation can be achieved inserting two wires in sagital plane, on the ring mounted few centimeters above distal ring, connected with extension to rings or using the same telescopic frame which links proximal ring.

Rings are connected with telescopic frames, which should be parallel and at equal distance from the bone.

Performing proximal corticotomy, proximal ring should be placed to diaphysis at angle of 300 to 400, in order to prevent varus and antecurvatum deformities. More stability can be achieved by additional ring with



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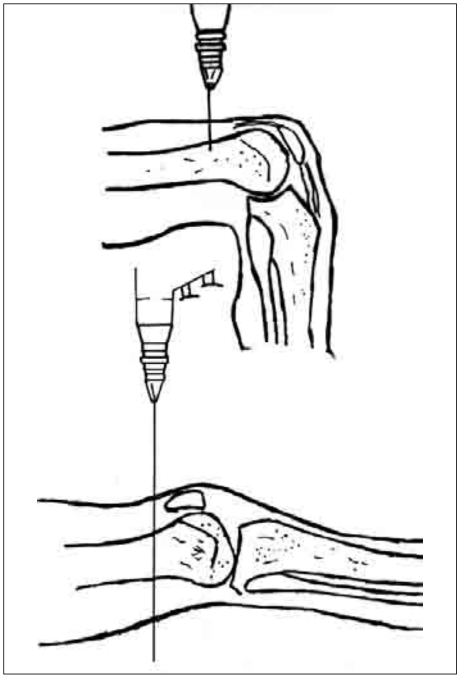


Shema 7.

Kirscher wire, placed in the middle of diaphysis.

Indications for distraction osteogenesis of femur, on two sites simultaneously, is indicated in cases of bone defect or limb abbreviation of more than 7 cm. However, is is recommended to bridge extensive bone defects in few subsequent interventions. Full range of moment should be achieved following every distraction osteogenesis and compensation of bone defect. Method should be repeated on the same bone not earlier than 6 months upon fixation dismantling.

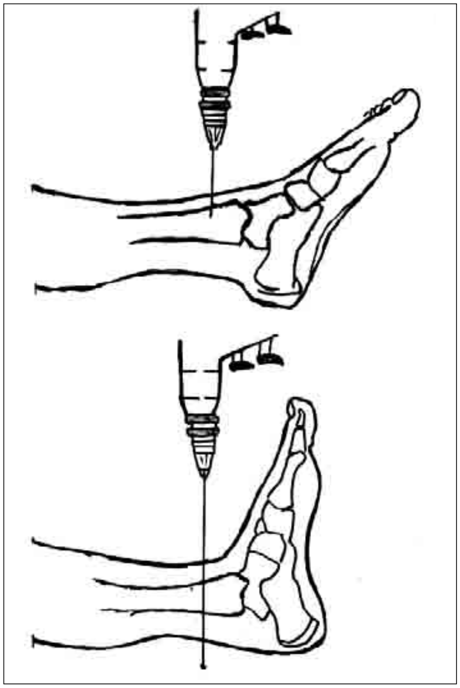
6.3.4. Application of fixator with wires on lower leg

Distraction osteogenesis is feasible on lower leg is patient is more then 5 years old and bone defect measures over 3 cm.

Simple anatomical orientation on bellow knee allows Kirschner wires insertion proximally to tibial dyaphises at angle of 90º. Proximally, it is sufficient to insert two Kirscher wires, crossing in horizontal plane at angle of 50º to 60º, wires are tensioned and fixated to the ring. The third wire can be inserted in frontal plane, 2 cm more distally than the previous two and then to fix with two distancers, mounted on the ring. If needed, one wire can be inserted through both bones, through tibia and head of fibula.

If planning high coritcotomy and production of more then 5 cm of new bone, by distraction osteogenesis, it is necessary to insert Kirscner wires under hypercorrection angle of 200, preventing antecurvatum.

Insertion of Kirscner wires through distal part of lower leg requires maximal plantar flexion in ankle (Sch. 8), placing wires from anteroventral side through skin, muscle and bone. Passing through bone, foot should be brought into maximal dorsal fklexion, passing wire through muscle and skin to posteromedial side of lower leg. These two tensioned and fixated Kirscner wires enable insertion of the third wire two centimeters proximally, in relation to them. The third wire is tensioned and fixated for two distancers, previously placed on the ring. Valgus is prevented by placing ring at 15º to 20º or using Kirschner wires with olive. Connection between two rings is ensured by four telescopic frames, which should be parallel to bone axis, providing an uniform stability.



Shema 8.

Distraction osteogensis of lower leg, in one intervention and two levels, is indicated in abbreviations more than 7 cm or in deformities. In such cases, application of three rings is required, while satisfactory stability may be achieved placing two Kirschner wires in the ring.

All wires must be properly tensioned to fixator ring, which should not be closer than 3 cm to skin, due to edema.

Tensioning is accomplished with screw with groove on the ring, which is tensioned by wires loading and pressure. With ring placing, bone must be in the center and soft tissues equally distributed around the bone. Rings must be parallel to nearby joints and telescopic frames, connecting rings, must be parallel to bone axis. Such procedure ensures adequate stability of bone fragment and an uniform loading to all wires. Number of wires is minimal yet sufficient to ensure stabile fixation.

Following frame mounting, while the patient is still under anesthesia, even the most experienced surgeon should test for maximal range of motion and perform addition incision around wires, if skin is tensed.

7. SEGMENTAL BONE TRANSPORT BY DISTRACTION CALLUS

Extensive bone defects on partially and poorly vascularsites present a problem for a surgeon who is faced with limb repair task, desirably resulting in functional efficacy and mechanical stability. Under such conditions, incorporation of cancellouss, cortico-cancellous or cortical autograft carries a low possibility for successful bone loss repair. Even if incorporation takes place, original tubular bone shape is not reconstructed, then a solid column of the bone is formed. This column is usually place of locus minoris; it allows possibility for re-fracture of host bone, graft itself of development of pseudoarthrosis. Vascular bone grafts place a great demand with regard to surgical skills, equipment, time,… All these techniques re limited by quantity and size of available autograft, then by high complication rate.

There is an alternative to attempts to compensate for bone defect using autogenous grafting - it is segmental bone transport by distraction callus. This method is used if bone already exist on the spot. It does not require bone autograft or homograft, transforming partially osteogenic soft tissue into highly osteogenic tissue.

There is an alternative to attempts to compensate for bone defect using autogenous grafting - it is segmental bone transport by distraction callus. This method is used if bone already exist on the spot. It does not require bone autograft or homograft, transforming partially osteogenic soft tissue into highly osteogenic tissue.

Huge bone defects resulting from trauma, infection of tumor resection, may be regenerated by simultaneous distraction osteogenesis and by transportation of viable bone segment over bone defect. This multifocal treatment includes distraction and final compression of transported bone segment to other bone segment. Transport may be performed proximally, distally and transversally.

Method of segmental transport commences on the level of remaining long bone with preserved, viable soft tissues. Following 1 - 1,5 cm skin incision and corticotomy, this segment moves toward the zone of bone defect with speed of 1 mm per 24 hours. Movement is ensured by adequate traction mechanism produced by external fixation. Considering this biological principle, e.g. that every surface of corticotomized bone has a blood supply and performing distraction in regular rate, rhythm, respecting latency, with stabile external fixation, we expect distraction osteogenesis to produce new bone which will soon remodel into a normal bone.

Fig. 8.

On corticotomy site, bone is gradually elongated, extended and consequently decreases the size of original bone defect. Response to traction within this zone of distraction is a normal bone. With time, this bone shall, by processes of mineralization and increased mechanical load, transform into a lamellar bone. At the same time it will preserve original shape of tubular bone. Process of bone remodeling does not ceases with distraction osteogenesis termination. External fixation must remain positioned until new bone is formed, roughly, at liest two to three time s longer then necessary for bone transport.

When entire defect is bridged, moved segment will, on the other part of long bone, create pseudoarthrosis (Fig.8). Osseous union is ensured by re-assembling external fixator and establishing adequate compression forces between bone fragments.

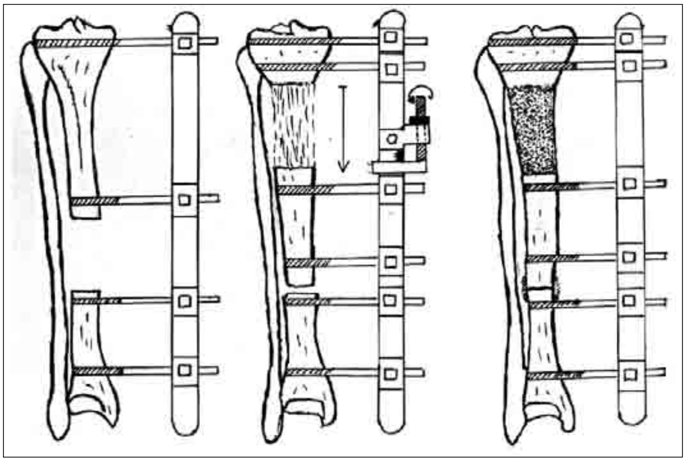
Segmental transport should not be considered within primary surgical treatment, then it should be considered within secondary, definitive treatment, only after process of soft tissue healing has commenced.

7.1. Segmental bone transport by AO external fixator and Schanz pins

AO external fixation in primary surgical treatment for stabilization of long bones fragments is frequently used. On the existing external frame, an additional AO-compressive apparatus is fixed. Then, Schanz pins are placed on the apparatus, pins already being inserted into a segment to be transported. Next, corticotomy is performed.

Following corticotomy, segment can daily be moved by tensioning compression apparatus. Distraction rate in this apparatus is 1,15 mm (Sch. 9).

The weak side of segmental transport with this fixation is the fact that compression apparatus does not allow



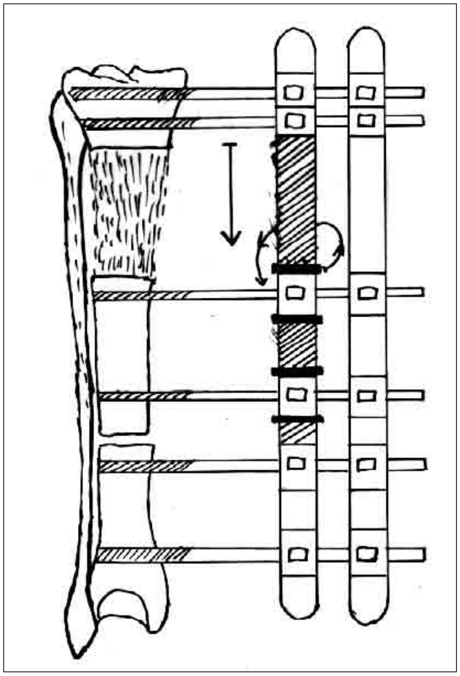
Shema 9.

distraction of more than 3 mm. Schanz screws should then, by clasps tensioning, fixed to the tube sliding along the fixator frame. Shifting Schanz pins they derange soft tissue bellow and require additional incisions for free pin passage. Pins leave a track of granulating tissue, a tissue vulnerable to infection. When defect is bridged and corticotomy space filled, it is necessary to anchor segment opposite to defect end. Often, on this site soft tissue is "interposed", leading to delayed union or pseudoarthrosis. If so, incision is done, soft tissue moved away and, if necessary, to perform bone grafting in order to promote union. When segment apposition on bone end is achieved , Schanz pins may be fasten on fixator frame and compressive apparatus then removed.

Weak technical performances of this fixator and possible complications of soft tissue, leave the use of it for short bone defects, 3 to 5 cm in size.

7.2. Segmental bone transport with thread of AO external fixator frame

Transport system with this type of external fixation is based on almost the same principles of bone transport described for AO-external fixation and Schanz pin. Compression apparatus is replaced by threaded rod, placed bellow the long tube of unilateral external fixator. (Sch. 10) two Schanz pins performing transports should not collude with long tube and clasps.



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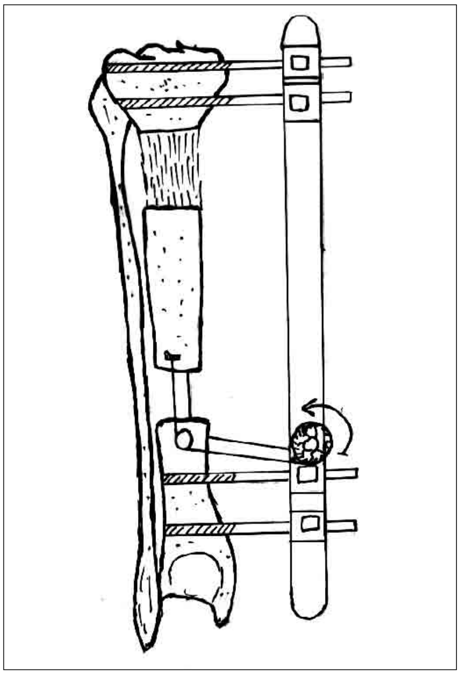

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7.3. Segmental bone transport with traction wire of the external fixator with pins

In order to avoid soft tissues complication occurring when Schanz pins are used for distraction osteogenesis, an internal traction mechanism is mounted under the skin. Mechanism of internal traction is composed of two wire, 11,5 mm in diameter, fastened for bone segment which undergoes distraction via mechanism of loops fastened with two small A0-screws. At defect end, this traction is directed by two leading screws, each of them with head whole and wire brought out to external fixator and fixed to cog-wheel. (Sch. 11)With daily motion of this cog-wheel, segment is moved for 1 mm. Upon termination of distraction, tensioning wires are removed and moved segment is fixed to previous two, long with mandatory bone autografting. It is important to say that firstly A0-plate is placed and only then traction wires removed. In opposite case, segment would slide back to corticotomy level and would be impossible to restore its correct position in defect.

Wires have constant and fixed exit point from the soft tissues, allowing surgeon to work slowly, in no rush, resections of devitalized tissue, along with parmanent insight into soft tissues and bone condition.

7.4. Segmental bone transport with Mitkovitch M 20 external fixator and traction wire

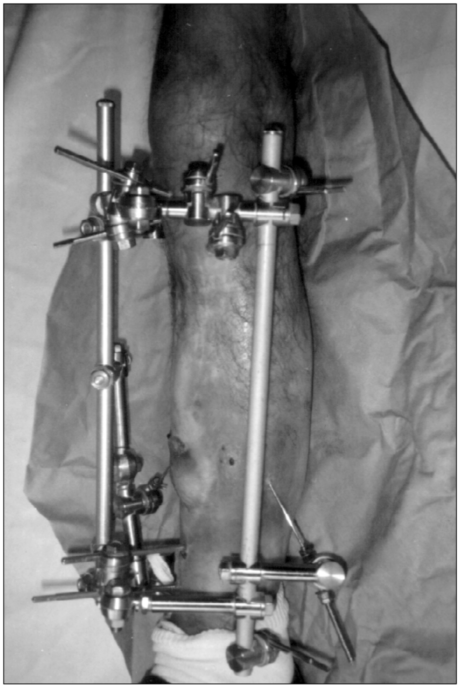


Fig. 9.

Fig. 10.

Fig. 11.

Prof. dr Milorad Mitkovich constructed M 20 external fixator in Nish, 1991. It is unilateral type of fixator with pins. Great mobility of movable connection and pins allows various mounting of the frame and adequate stability of fractured bone, with or without bone loss. Construction of joint tensioning device, placing opening to movable connections, allows placement of telescopic frame, 4 mm thick, to movable connections and to place foreseen for the pin. These expand therapeutic possibilities of this fixator. (Fig. 9)

Upon soft tissue healing, corticotomy is performed (Fig.10). By placing joint tensioning device, stability of fractured fragments increases and telescopic frames on places for pins, ensure that wires doing bone transport, maintain permanent fixed exit point from the soft tissues. After latency phase, daily distraction of 1 mm is done, as well as physical therapy. Weight bearing is graded and gait allowed only using axillary crutches. When complete bone transport and contact on bone ends are accomplished, (Fig. 11), it is sufficient to maintain biocompression by telescopic frame. Such compression on the contact site will lead to segment incorporation into bone ends. (Fig. 12) There is no need for additional surgical interventions, for bone grafting or for mounting some other type of external fixator. Adequate physical therapy permits full weight bearing and knee and ankle range of motion, even before the fixator is dismantled. (Fig. 13)

7.5. Segmental bone transport with unthreaded medullar pin

The use of unthreaded medullar pin for bone fragments stabilization in open fractures , with or without bone defect, gains more and more sympathies among surgeons, due to good results. Its use and segment distraction must be planned during the course of primary surgical treatment (Fig. 14). To provide adequate stabilization of fractured fragments with medullar pin, the pin must be "locked" proximally and distally with cortical screw, going trough both cortices and medullar pin. Such method ensures adequate stability of bone fragments and maintains limb length.

Upon soft tissues healing, an fixator with system of bone transport is mounted, corticotomy is performed and , following latency phase, distraction may commence. Osseous segment slides along the medullar pin; dislocation is prevented. When segment distraction is finalized, continuos fixation of segment must be

Fig. 12.

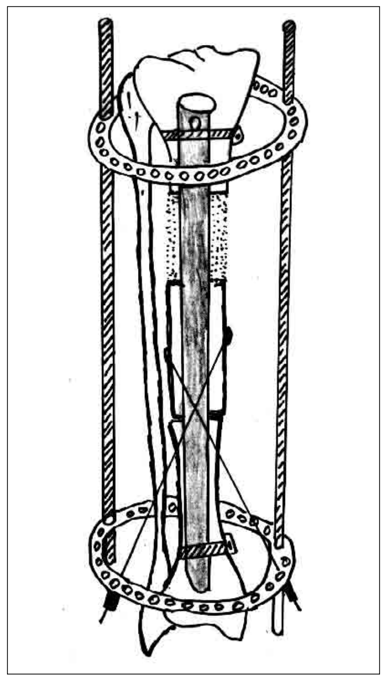
Fig. 13.

7.6. Segmental bone transport with external fixator with wires and crossed Kirschner wires

Ilizarov performed his technique of bone segment distraction using his ring fixator with, 1,8 mm Kirschner wires. For this purpose, Kirschner wires are tensioned on metal rings while rings are distributed along entire bone diaphysis and inter-connected with shredded rods (telescopic frames) . An elastic system is created between individual rings and bone is fixated and stabilized against friction within. In long bone diaphysal defects, two rings are used for fixation of the proximal bone end, two rings are used on distal bone end and one ring for segmental transport purpose. (Sch. 13). Such mounting of external fixator provides adequate stability, distraction, possibility for rhythm follow up and bone segment can not dislocate.

Segment is transported following corticotomy, changing threads on screws of telescopic frames. Doing so, Kirscner wires cut soft tissue but process of segmental transport causes less damage to the soft tissue then if Schanz pins are used.

The advantage of this rings system is allows that, upon achieving desired position, segment may be compressed

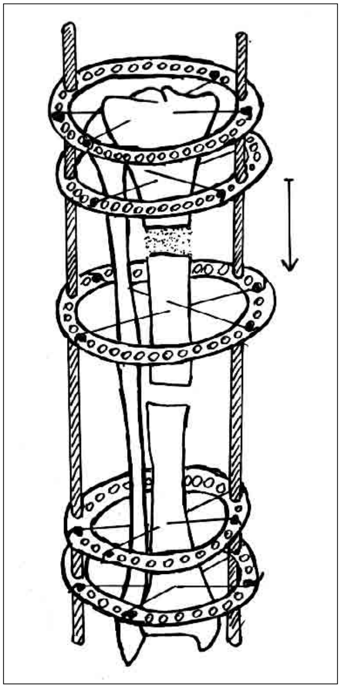


Shema 12.

ensured. It is accomplished by retaining external fixator on site, thus transporting system produces biocompression between bone segment and bone ends. The other possibility is to remove fixator and fasten the position with cortical screw. (Sch. 12)

Medullar pin with screws provides adequate stability to new bone formation within the zone of corticotomy and bone regeneration may continue. There is no need for additional stabilization system.

Fig. 14.



Shema 13.

towards anchoring site , with ring only. For this, cancellous autografts are usually not needed. Also, there i no need for surgical intervention to obtain union. From the biomechanical aspect, this frame is capable of full weight bearing and this load - weight of the limb, stimulates formation of the new bone. (Fig. 15)

Disadvantage of this fixator are its enormous size and weight.

7.7. Segmental bone transport with external fixator with wires and Kirscher wires with olives

Compared to majority of traction systems, disadvantage of previously described transport lies in the fact that Kirschner wires should slide across soft tissue layers to a great length. This causes pain and may lead to infection.

To avoid this cutting through soft tissue layers, Ilizarov developed special wires with olive shaped ends. Olives are inserted into segment undergoing transportation. Olive shaped ends prevent wires to slide trough the bone. These wires may be brought out , into subcutaneous layer of the soft tissue, toward distally and then tensioned by traction mechanism, fastened in a distal ring. (Fig. 16) The track made by Kirscher wires cutting into soft tissue is limited to few millimeters and further trauma is prevented. When segment reaches desired position, , a good inter-fragmentary compression between segment and distal bone end is achieved with olive wire. To accomplish adequate stability of long bone diaphysis, two rings are used on proximal and on distal bone ends, respectively. (Sch. 14)

7.8. Bone shortening and callus distraction

During primary surgical procedure limb may be shortened for a distance of given bone defect length. Such procedure ensures better consolidation of soft tissue and mutual adaptation, bone end healing. It guar-

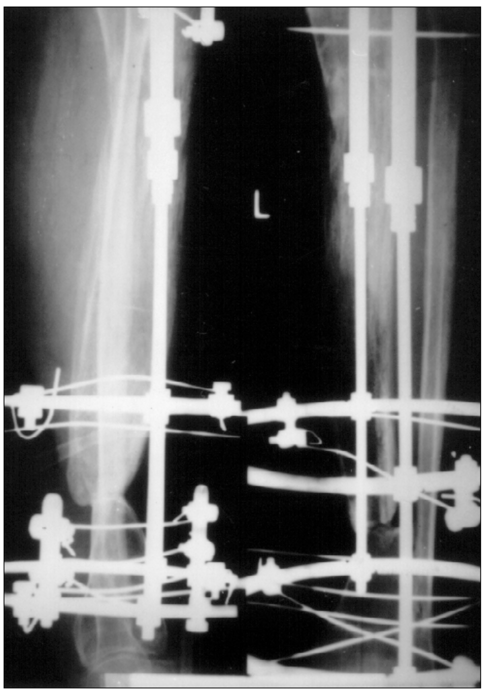
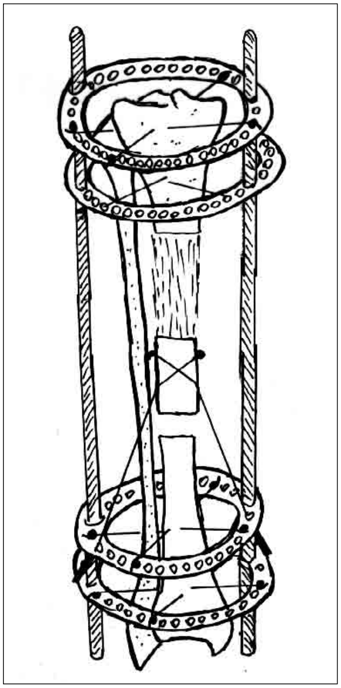


Fig. 15.

Fig. 16.

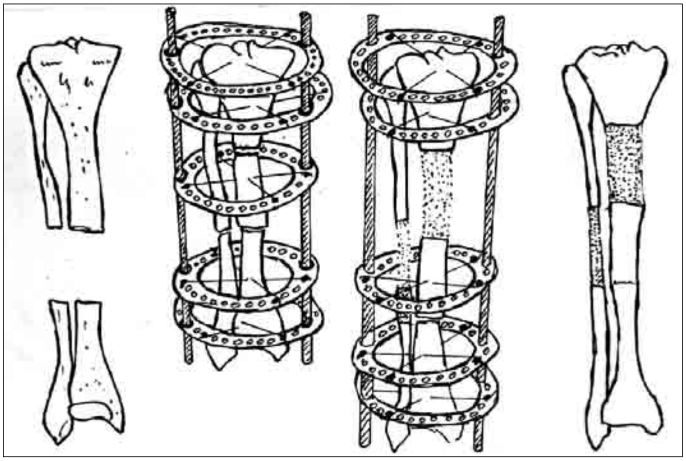


Shema 14.

antees soft tissue healing and consolidation of the broken bone.

To compensate for abbreviation and to establish the original limb length, first is corticotomy performed in healthy soft tissue, far from the soft tissues lesion. This is done following stabilization with Ilizarov fixator. After the latency phase, with 1 mm of daily distraction , the original length of the bone diaphysis may be reconstructed. (Sch. 15)

This method can not be used for defects less than 5 cm due to soft tissues retraction and consequent stiffness in nearby joints.



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8. NONUNIONS AND DISTRACTION OSTEOGENESIS

Ilizarov divides nonunion into two broad categories: stiff and loose

8.1. Stiff (hypertrophic) nonunions

A stiff nonunion corresponds to hypertrophic nonunion. There is usually pain on motion of nonunion and feeling of resistance to manual deformation at the fracture site. Roentgenograms of a stiff nonunion reveal proliferative callus growing out from the fragments on both sides of the fracture line. (Fig. 17)

If considering histology and physiology of hypertrophic pseudoarthrossis, which has good vascularity and viable bone ends, strongly joined with fibrocartilaginous surface, it looks very much as distraction osteogenesis. Direct primary distraction via hypertrophic nonunion, causes ischemia with lysis of fibrous and cartilage tissue. This stimulates and re-vives osteogenesis, where compression leads to direct , rapid , angiogenic union. Not only is osteogenesis stimulated, then with frame manipulation in one act the exiting deformity is corrected as well. Gradual application of distraction and compression in these cases, by standard rate and rhythm, provides biological optimum for the bone consolidation.

Fig. 17.

8.2. Loose nonunion

Loose nonunion corresponds to atrophic nonunion. A loose nonunion moves easily during manual examination on the fracture site. The patient often experiences little or no pain. On roentgenograms, the atrophic bone fragments are with no evidence of callus formation. (Fig. 18)

Atrophic pseudoarthroses require an additional procedure. Considering that bone ends are usually hypovascular and often contain dead bone with fat interposition, primary distraction will not stimulate osteogenesis. Primary compression, with or without open debridement on the defect site, with additional corticotomy (bleeding corticotomy) of the same bone, must ensure an increased local blood flow and source of a new bone, for compensation of the lose length. Medullar fixator is easily adjusted for multifocal treatments, such as simultaneous distraction osteeogenesis and compression on the nonunion site.

8.3. Pseudoarthrosis , contractures and distraction osteogenesis

Acquired joint contractures or joint ankyloses are serious problems resulting from external fixation of diaphyseal fractures, with preserved joint surfaces or with intraarticular fractures. (Fig. 19)

Lack of surgical experience, inadequate stabilization and absence of motion in the joint, lads to progressive fibrous joint degeneration, associated with muscle shortening and atrophy. Problem is even bigger, if

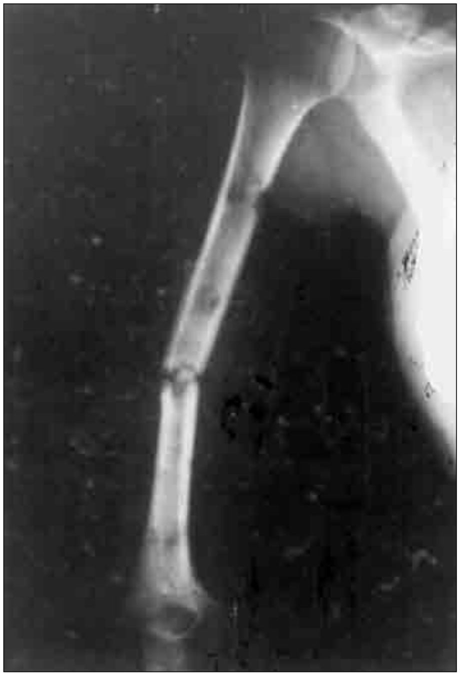


Fig. 18.

Fig. 19.

one of the bones forming the stiffed joint , did not heal.

Congruency of articular bodies and preserved joint space indicate reality of joint motion. Patient must be motivated, with desire for normal gait, with no limping. Patient should also be informed in advance about efforts required to prior to regular joint movements. If cause for ankylosis is not cured (Fig. 20), it should be. Construction of external fixator should be such to provide and ensure consolidation and gradually, full range of movements. (Fig. 21) When applying Kirschner wires, as much as possible of the soft tissue should be provided, by folding it toward the side of shortening. The key moment when placing Ilizarov apparatus in joint contractures treatment, is placing the axis of fixator articulation and the joint axis into a same plane. This will ensure gradual, uniform and progressive joint unloading , by controlled distraction. Necessary distraction of the joint is 1 to 2 mm. On radiography, prior and after apparatus application, we follow up weather distraction is satisfactory. Huge mobility of distraction, artificial joint and Kirschner wires with olive - all found in Ilizarov fixator, allow simultaneous treatment for pseudoarthosis and joint ankylosis.

Contracture is managed by flexion-extension telescopic frames, with artificial joints, with axis going through the joint axis. Changing screw for 1 mm on telescopic frame, equally corresponds to 30 0 of flexion. Physical therapy should commence immediately. In 10 - 15 days,

Fig. 20.

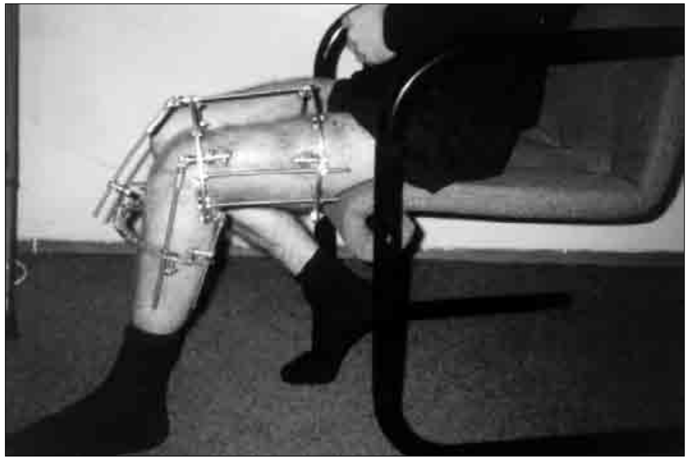


Fig. 21.

achieved ROM, approximatelly 300- 400 is maintained with physical therapy. During the night the joint is placed into maximal ROM position. (Fig. 22 a) Abence of pian may facilitate joint motion, while pain have an opposite effect and may lead patient to stop treatment.

In second course of achieving full ROM, daily increase on telescopic rods may be 3 - 4 mm or 90 to 120. Treatment may last 7 - 8 weeks, depending on contracture, patient's age and actual joint damage. Fixator is carried until full, painless flexion-extension is achieved in the joint, feasible with apparatus on and within few minutes. When full function is established with apparatus, patient should continue with active exercises with apparatus and joint unloading (eliminating pressure on soft tissues and joint surfaces) for about 10 - 15 days, then apparatus is dismantled and active physical therapy proceeds.

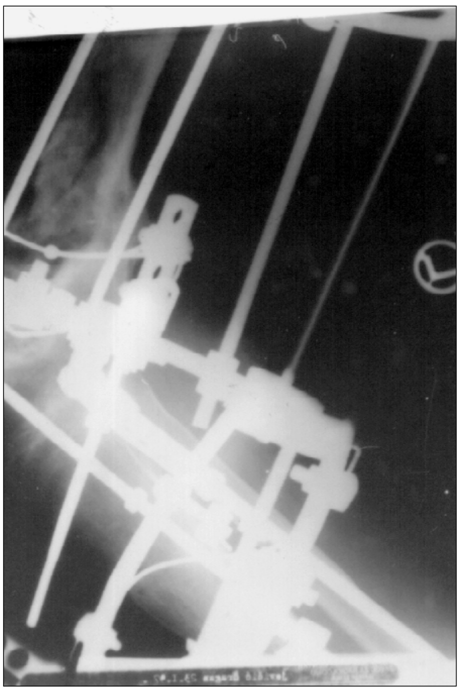


Fig. 22a.

Fig. 22b.

8.4. Distraction arthrodesis

When extent of joint destruction (due to extent of trauma or due to etiology) does not permits reconstructive procedure or aloplasty , often , the only acceptable solution is feasible with distraction osteogenesis. (Fig. 23)

Apart from osseous joint fusion, distraction callus retains adequate limb length and joint angle. It further ensures consolidation of severe joint conditions and cessation of pain. Despite arthrodesis in one joint, continuity and function of the limb, threatened by amputation, is established.

Fig. 23.

9. DEFORMITIES AND DISTRACTION OSTEOGENESIS

In orthopedic surgery, a limb deformity is a deviation form the normal anatomy. The deformity may include abnormalities of length, rotation, translation or angulation. Several other components of limb deformity should also be considered in individual cases: deficiency, malformation, contour, circumference and proportion.

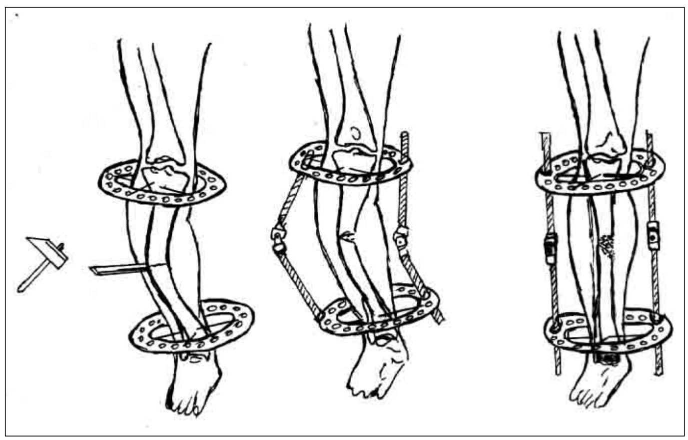
Surgical treatment of deformities was characterized by an aggressive stand and internal stabilization was associated with great exposure of bone and soft tissues to external environment. Some deformities had to be dealt with in several consequent interventions, and thus led to an increased risk of soft tissues damage, distension, paresis, infections…

Correction of deformity : by externl fixaton, atraumatic corticotomy , by application of pins or Kirschner wires, insignificant infection rate and achievement of full, desired limb length, imposed distraction osteogenesis as a dominant method in deformities treatment. Circular fixator maintains technical control on bone fragments in three planes, simoultaneosuly allowing for 60 of freedom so angular and translational corrections are feasible, as an addition to the standard axial distraction. Method is ideal for angular lengthening as well as for partially restriction of the growth.

In deformities up to 300, regardless angulation, rotation following stabile fixation with external fixator and performed corticotomy, correction of deformity may be performed intraoperatively. [7,12]

In deformities with more than 300, correction must be done gradually, continuously. One corticotomy may be used for deformity correction and inequality treatment.

Rings are placed parallel to joints, and telescopic frames follow bone diaphysis. On the angulation sites, joints are placed around longitudinal axis of the telescopic frame. (Sch. 16) Joint plane is placed in the same plane with telescopic frames, into desired correction plane. [26,28] Corticotomy is performed on the top of the angulation. After the phase of latency, distraction happens equally, on all telescopic frames, until distraction of 2 cm is achieved. With 2 cm of achieved distraction, on the shorter side an asymmetric distraction of 0,25 mm 4 to 5 times a day, is done, until rings of external fixator are brought into horizontal plane. Telescopic frames correct deformity when frames



Shema 16.

are mutually parallel and parallel to the bone axis. [40,41,43] If, beside the angulation, limb inequality should be dealt with, distraction is uniformly continued on telescopic frames. Upon deformity correction, telescopic frames with joint may be replaced with "ordinary" frames, without joints.

Correction of minor deformities , in more planes, on one long bone , is feasible in one surgical intervention. It is necessary to perform an adequate number of ciorticotomies and, with the external fixation, to achieve an adequate stability of corticotomized bone fragments. [12,13] large deformities, in few planes, require gradual treatment and correction of the most sever deformity in one plane, then the other, until complete correction.

High subhondral, extraarticular or intraarticular corticotomies are performed in distal femur or proximal tibia, next to the joint up to 1 - 1,5 cm. In case of proximal tibia, then an extraarticular osteotomy is performed within (interliganmentous) or outside (extraligamentous) attachment of joint capsule. Such corticotomis are feasible if an adequate stability of bone fragments is ensured by external fixation, following corticotomy.

Large osseous intraarticular defects sustained in war- or peace-time trauma, jeopardize function of the limb prior to prosthetic fitting, if feasible. (Fig. 24). Setting a good strategy, using the possibilities of distraction ostegenesis and respecting technical principles of the chosen method, disability may be diminished. (Fig. 25)

10. INEQUALITY , LOW GROWTH AND DISTRACTION OSTEOGENESIS

Inequality and the low growth bellow 1,5 m do not pose serious problem for the individual in community. In case of limb discrepancy, abbreviation of one limb for more then tolerated 2 cm, various disturbance in static and dynamic functions of the locomotor system will occur. Limb shortening leads to pelvic angulation toward the side of shorter leg, and lumbar spine follows this curvature.

An upper limb shorten for more than 3 cm, is an obvious cosmetic defect and leads to the functional, permanent angulation of the thoracic spine and to the weaker development of shoulder griddle.

More and more authorities consider distraction osteogeneis as a supreme method in inequality treatment, weather for equalizing the limb length discrepancy or for the low growth treatment. Recent report inform about limb lengthening even up to 35 cm. [1,20,40,41,44] Principles of surgical technique are the same in all authors, but the schedule of long bones elongation in low growth differs in different authors.

De Bastiani thinks that in lower limb elongation , the best choice is crossed application of his external

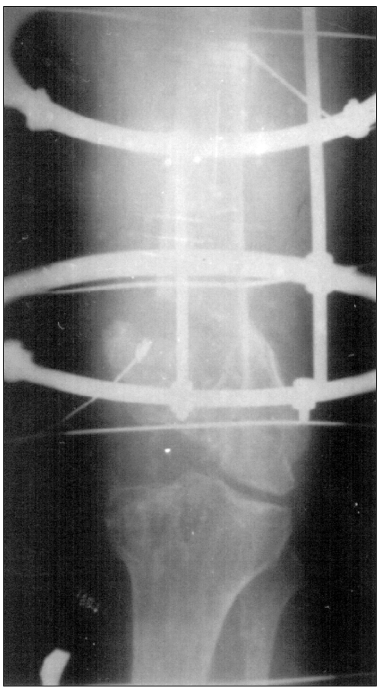


Fig. 24.

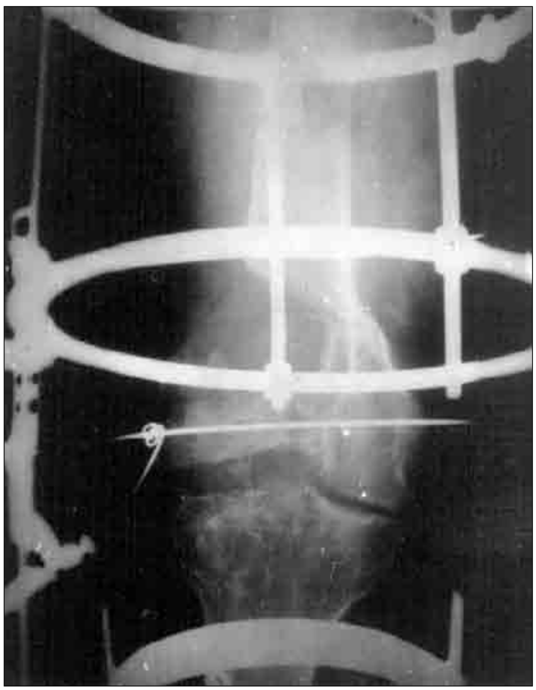


Fig. 25.

fixator with pins - : left femur; right tibia or left tibia - right femur . Such procedure allows better control over the long bone axis nd retaining that axis until mature callus is formed.

Ilizarov states that best method for elongation is to place his fixators with wires on both lower legs. Following elongation on both lower legs, elongation of both femurs should be attempted. Gain and weight bearing are mandatory.

Villarubias agrees with Ilizarov but recommends no weight bearing.

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III

VASCULAR AUTOGENOUS BONE GRAFTS

INTRODUCTION

Progress of orthopedic reconstructive surgery in the last ten years places more and more demands for bone autograftig procedures. Due to a limited quantity of available cortico-cancellous bone autograft, vascular-bone grafts are used more and more often.

Technical development of materials for internal bone fragments stabilization and achievements in microsurgical technique allowed successful animal experiments with transplantation of bone grafts holding their own artery-venous system.

In 1973 McCullogh successfully reconstructs mandible defect using vascularized rib graft and microsurgical technique. Ueba and colleagues transplanted, in 1974, first vascularized fibular graft in Japan and Taylor and co-workers in 1975 report on successful results in using vascular fibular graft for extensive tibial defects. In 1981, Teot and colleagues presented their results on using vascular bone autograft, obtained from the lateral scapular edge.

Developmental process of axial, musculo-cutaneous, facio-cutaneous , osteo-mio-cutaneous and osteo-septo-fascio-cutaneous flaps is based on modern concept of vascular anatomy , a ground for the free vascular bone autografts. [14] Modern concept of clinical anatomy, development of microsurgical technique and more and more frequent utilization of microvascular tissues, resulted in clinically simple classification of flaps into :

I - Pedicled flaps

1. Local flaps

a) sliding flaps

b) transposition flaps

c) rotational flaps and

d) insular flaps

2. Distant flaps - with no flap anoxia on recipient defect

a) tubed flaps

b) crossed flaps

II - Free flaps - revascularization of donor flap is established by microsurgical anastomosis on recipient defect (14) :

1. cutaneous flap

2. muscle flap, musculocutaneous and osteomyocutaneous flaps

3. Fasciocutaneous and osteoseptofasciocutaneous flaps.

I - VASCULAR BONE AUTOGRAFTS

Vascular bone autograft is defined as a graft being transplanted to a host site along with its own blood supply; with its nutritive blood vessels or as a bone graft lifted on cutaneous or muscular pedicle. Nowadays, vascular bone lifted on cutaneous pedicle are less used due to poor bone vascularization.

Vascular bone autograft ensures osteocytes vitality, mechanical bone compactness and incorporation potential. Process of the new blood vessels ingrowth is partly dependent on the osteogenous vascularization of the host site. Process of the new blood vessels ingrowth from the host site into a graft will, to the great extent, depend on host site vascularization.

1. HOST SITE IN TRANSPLANTATION OF VASCULAR BONE AUTOGRAFTS

Quality of the host site vascularization is crucial for vascular graft incorporation and will depend on: patient's age, on the extent and type of trauma and on the ability of tissue to react to pathological factors.

Receptor or host site of the vascular graft is classified into: highly osteogenic, partially osteogenic and non-osteogenic place. Although vascular graft does not depend greatly on host site vascularization, graft incorporation can be improved for 20 - 40 % if receptor site is an highly osteogenic site (Hirrner et al., 1991)

Size of defect and type of trauma influence the choice of donor site.

2. STABILIZATION OF VASCULAR GRAFT

Adequate stabilization is essential for rapid and favorable graft incorporation into a bone defect .

Attempts to avoid micromotion on proximal and distal interfaces of graft are futile. Wood and colleagues (1985) proved that , in long bone defect, rate of delayed union decreases if stabilization of vascular bone graft is achieved by external fixation.

The advantage of grater stability is in opposite balance with weakness resulting from greater devitalization of the host bone and vascular graft occurring on the edges, due to presence of fixation device. Using posterior approach, tibial defect is bridged from the AO plate, placed parallel to the graft. With three cortical screws, plate is fixated proximally and distally. Stability increases if screw is placed in vascularised autograft as well. Results are stabile internal fixation and an addition support which partially relieves vascular bone autograft. Insertion of cancellous bone on proximal and distal ends of the graft can significantly promote graft incorporation. Applying the cancellous bone along entire graft length is not useful, since cancellous bone will resorb in the middle of bone defect. Shortcoming is possible reduction in blood supply which further can play role in delayed graft incorporation.

Vascular graft responds to loading with internal modeling and hypertrophy more rapidly and more efficient then non-vascular graft and it is the main advantage of vascular grafts.

Problem of graft fixation to the insertion site is still without satisfactory solution and there is no common stand. It is no possible to make definite conclusions on optimal graft fixation.

3. INCORPORATION OF VASCULAR GRAFT

Due to a fact that musculo-periostal vascularization and bone vascularization are not interrupted or are only temporarily interrupted, most of the vascularized graft tissue remains undamaged. This results in sufficient quantity of viable graft and in small quantities of necrotic bone which conditions and leads to the more intense bone regeneration in osteoblastic stage of graft incorporation. Internal graft structure is preserved, circulation is established, thus process of remodeling - graft incorporation can start immediately.

Process of vascularized graft incorporation is similar to process in segmental fracture. Incorporation starts with osseous tissue resorption, primarily followed by reactive apposition of the compact bone which is secondarily being replaced with the lamellar bone. Due to preserved internal structure of the graft, process of remodeling can start with no delay.

Described characteristics can be histologically verified. Histological evolution indicates an early and extensive penetration, interlacing of the graft bone with bone of the host site.

Radiological examination shows smaller and more extensive callus (secondary ossification) , on graft and host bone interfaces . Enhanced callus formation leads to more rapid and more strong bone union.

4. FRACTURE OF VASCULAR GRAFT

Stress fractures of vascular grafts are to be found in 10 to 25 % of cases, regardless if iliac crest or fibula graft were used. Fracture should be managed in the same fashion as the host bone fracture. In up to 10 % there is a need to second surgery, insertion of cancellous bone in order to facilitate fracture healing and graft incorporation.

II - ADVANTAGES OF VASCULARIZED AUTOGRAFTS IN COMPARISON TO OTHER AUTOGENOUS GRAFTS

The main advantage of vascularized grafts are own, proper blood supply and thus increased number of osteogenic cells and osteoinductive substance. It allows for more intense regeneration in osteoblastic stage of the graft incorporation. Compared to non-vascularized graft, vascularized graft responds to loading with internal remodeling and hypertrophy more rapidly and more efficiently.

Osseous and musculoperiostal vascularization in vascular graft is not interrupted or it is only shortly interrupted. Most of bone tissue is preserved and possesses bigger quantity of viable graft and less necrotic bone - if compared to non-vascular bone grafts. Small proportion of necrotic bone in vascular graft will result in less erosion due to bone resorption.

For preserved internal structure, remodeling process can start at once. Vascular graft adjusts to altered mechanical conditions more rapidly then non-vascular graft.

Permanent blood supply means that graft is more resilient to unfavorable conditions; to the presence of partially osteogenic site or non-osteogenic site, to poor vascularization in the host or to infection exposure. With blood supply, antibiotic is more available, as well as lymphocytes of immune system…

Vascular graft can respond to own needs, also it can vascularize, by it self and to a certain extent, a bone with poor blood supply or necrotic bone. Intact blood supply in bone graft increases chances for survival, in other words, incorporation. In bone loss management following tumor resection, transplantation of vascular bone shows better response to postoperative irradiation therapy then it is case with callus distraction.

Disadvantages of the vascular bone autograft are:

- it requires extensive preparations, multidisciplinary approach to the problem;
- it requires excellent microsurgical skills.

III - VASCULAR AUTOGENOUS BONE GRAFTS

Treatment of bone defects over 6 cm in size with cancellous , corticocancelous bone graft often leads to prolonged treatment and to an uncertain treatment outcome. In such situation, a use of vascularized bone grafts , where bone preserves its blood supply should be considered. If repair is done within optimal time, in one or two surgical interventions, and using optimal reconstructive technique, the treatment outcome will be satisfactory. In bone defects reconstruction practice, most commonly used vascularized bone autografts are vascularized graft of iliac bone and fibula.

There are following vascularized bone autografts :

1. Muscle pedicled graft (bone graft lifted on muscular pedicle)

2.Vascular pedicled graft (axial flaps are vascular-bone grafts which are transplanted along with their nutrient artery);

3. Free vascularized bone grafts;

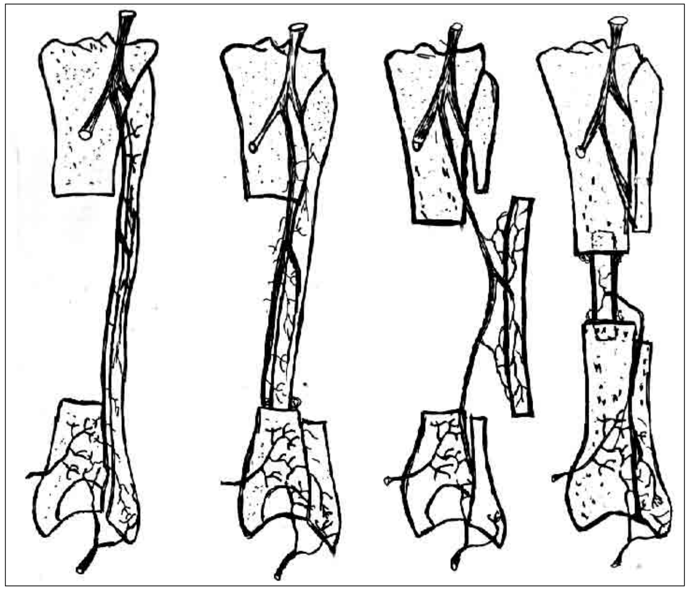
4. Bone grafts lifted on cutaneous flap - nowadays, less and less attractive due to poor bone vascularization.

1. MUSCLE PEDICLED AUTOGRAFT

The advantage of the muscle pedicled graft lies in no demand for microsurgical technique. Disadvantage is a loss of mechanical stability of the limb.

It is commonly used in tibial bone defect with an intact middle fibula segment (Sch. 1) . Preoperative angiography provides information on passage and anatomy of tibial and peroneal blood vessels which may also be damaged in injury associated with tibial bone defect. Attachment of nutrient blood vessels which vascularize fibula pass through the anterior tibial muscle.

Fibula is exposed through longitudinal incision and is dissected free with 0,5 cuff of muscle attachment, thus separating soleus and m. flexor hallucis longus on the posterior surface, m. peroneus on the lateral surface



Shema 1.

and m. tibialis posterior on the medial surface from fibula. Care must be taken to protect peronal blood vessels, which pass on the medial side of the fibula. The fibula is then transected proximally and distally, to give the correct length of graft required. Together with intact peroneal blood vessels, fibular graft may then be approximated to the proximal and distal ends of tibia and stabilized with two or three screws on each side, or with AO-plate and screws or with an external fixation. Cancellous bone graft should be obtained form the iliac crest and then placed on both ends of tibiofibular fixation to promote incorporation of the graft. Drains and closing wounds with no tension are mandatory. No weight bearing exercises should start early and weight bearing commences only when radiological evidence of tibiofibular union is present. (McMaster and Hohl, 1965; McMaster and Hohl, 1975).

Shortcomings of this method is loss of mechanical stability in the leg, stability previously obtained by intact fibula. The loss of intact fibula may also make the possibility of the creation of a tibiofibular synostosis.

A muscle pedicled bone graft taken from distal radius with an intact pronator quadratus attachment is often used to bridge small segmental defects of distal ulna.

2. VASCULAR PEDICLED BONE AUTOGRAFT

A common limitation of muscule pedicled graft is the relatively short vascular arch of bone graft which further restricts the area of local application. With presence of long vascular pedicle, a vascular pedicled graft may overcome this limitation and at the same time be applied without the need for microsurgey for transplanting the vascular pedicled bone graft with own nutrient arteries.

Available source of grafts with vascular arch even above 10 cm is the iliac crest graft. Commonly, it is used in defects of proximal femur. Vascular pedicle of this graft is composed of superficial iliac vessels, 0,5 to 3,0 mm in diameter ; superficial epigastric veins - 1,5 to 3,0 mm in diameter and deep circumflex iliac vessels. When harvesting osteocutaneous graft from the iliac bone , it is necessary to harvest a. and v. circumflexa ilium superficialis, vessels most responsible for vascularization of inguinal region. With relatively big diameter of artery and concomitant veins , graft is raised relatively easy. The length of the graft ,may be almost half of the iliac crest length since the deep circumflex artery reaches to mid- point of iliac crest, before it anastomoses with iliolumbar and superior gluteal arteries. Then graft may be transferred with 6 - 10 cm long pedicle, which easily reaches subtrochanteric region.

The advantage of this graft is its combination of cortical and cancellous bone, which provides both enhancement of graft incorporation and mechanical strength. It may alo be used as a composite graft to provide both soft -tissue and skin coverage.

Another, limited use of this technique is the forearm arm where distal radius or ulna can be used to reconstruct defects in this region, based on pedicles of radial or ulnar arteries (Leung, 1989).

3. FREE VASCULARIZED BONE GRAFT

Free vascular bone grafts are obtained with microsurgicl technique and then placed to the host bed, retaining their blood supply (own arterio-venous system). Microsurgical anastomosis on recipient defect ensures re-vascularisation of donor graft. Graft cells remain viable. Graft healing on the site of implantation is similar to the fracture healing and does not undergo creeping substitution stage. (Brunell, 1991)

Twenty years long experiences in using vascular grafts daily indicate their superiority in comparison to avascular methods of bone grafts. Advantages are as follows:

1. permanent union without necrotic bone and revascularization through the osteoinduction;

2."survival" of all graft cells, these cells are only temporarily deprived of own vascularity; osteocytes survive 24 hours anoxia; after 48 hours osteocytes die;

3. shorter period for the graft incorporation.

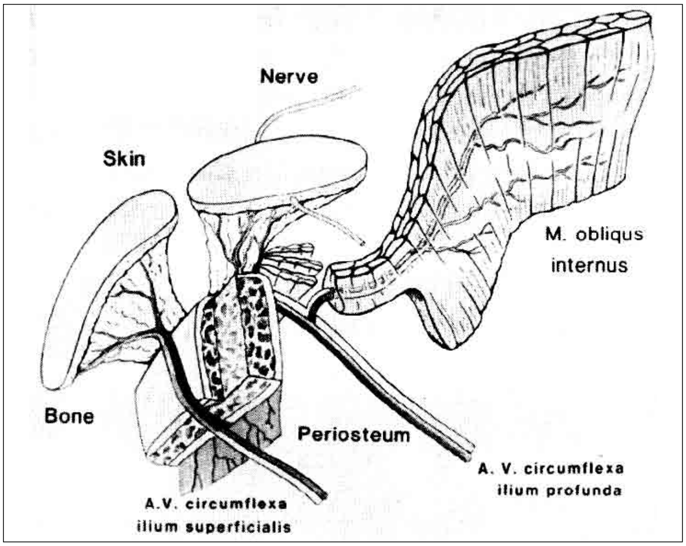
4. better tolerance to poor vascularization, to infection…

Common donor sites for the free vascularized bone graft are iliac crest based on deep circumflex blood vessels and the fibula based on fibular blood vessels. Other donor sites include the rib with intercostal blood vessels; then lateral border of scapula with descendent branch of circumflex scapular artery and distal radius based on radial artery.

3.1. Free vascularized graft of iliac crest

Free vascularized graft of iliac crest can provide up to 15 cm of cortio-cancellous bone , with 2 to 5 cm in width.

Anterior part of iliac crest offers various types of tissues: bone, periost, muscle, nerve, skin. (Sch. 2) Doubled blood supply of the bone, the extent and the quality of the soft tissue, expand its therapeutic utilization. Big part of surface is made of cancellous bone, which ensures better incorporation of the bone. Relatively big surface of crosswise diameter is especially suited for defects in articular areas of the joint and allows for better union on bone ends. Blood vessels diameter facilitates microsurgical techniques and diminishes complications. It can be used as an osseous-cutaneous graft in procedure for the limb defect, as well as for the mandibular reconstruction - although voluminous soft tissue may give unsatisfactory results.



Sch. 2 Available tissues when harvesting free vascularized graft from the iliac crest
Taken from AO/ASIF Scientific Supplement 1, INJURY 1994, Volume 2 S-A38.

To isolate the free vascular iliac crest graft, the origin of deep circumflex iliac vessels must be identified where they branch from the external iliac vessels, just proximal to the level of the inguinal ligament. Location of inferior epigastric vessels from the lateral side of external iliac artery, may serve as an landmark.. The deep circumflex iliac blood vessels can then be followed along their course toward the anterior iliac crest where they pierce fascia , passing along the inner cortex of iliac crest, giving out perforating branches for the bone. In order to retain these perforating branches during isolation of the graft, the three levels of abdominal muscles attached to iliac crest are divided on 0,5 cm superior to the iliac crest, thus protecting the vessels. Using subperiostal dissection, external surface of the graft then should be freed from m. tensor fascia lata and gluteal muscle. Iliac muscle is freed from internal cortex of the graft, and graft, on its vascular pedicle, can then be fetched with osteotome. The pedicle is then traanected, and anastomoses are relatively easy performed with double venous drainage.

If spatial relation of skin to bone is to extensive or to far from the iliac crest, then the skin flap may become necrotic. Distorsion of perforate blood vessels leads to reduction in blood supply or to the venous congestion in cutaneous part with consequent tissue destruction.

If abdominal muscles are closed and sutured in layers, morbidity of donor site is minimal.

3.2. Free vascularized fibular graft

In repairs of soft tissues and bone defects in limbs, fibula is preferred - weather as a vascularized graft or as an osteo-septo-cutaneous flap. [2,3] Fibula is cortical bone which provides excellent mechanical hardness and length for large segmental defects. [2,4,12] From proximal to distal parts, maximal length of 20 - 26 cm graft can be obtained.

The basis for fibular graft is based peroneal artery , which gives rise to nutrient fibular artery. [12,13] Along its flow, a. peronea (Fig. 1) forms the following branches:

- transverse communicative branch - for a. tibialis posterior, 6 cm above lateral malleolus peak;
- nutrient fibular artery - in 96 % of cases, nutrient opening is found in the central third of fibula, and in 4 % it is found in proximal part of fibula;
- medial branches for surrounding muscles, fibular periost, interosseous membrane;
- lateral branches, for fibular periost, peroneal muscles and skin;
- perforate branch, which penetrates bellow knee interosseous membrane and makes anastomosis with lateral tarsal branches of a. dorsalis pedis;
- lateral malleolar branches, which may have anastomosis with lateral tarsal branches of a. dorsalis pedis;
- calcanear branches, having anastomosis with calcanear branches of a. tibialis posterior.

Such vascularization provides doubled blood supply for fibula:

1. periostal, via medial and lateral branches;
2. endostal, via nutrient artery which enters fibula on its medial side, posterior to interosseous membrane, in second fourth, a bit proximal from the central point.

Difference in pressures between medular and periostal circulation, in physiological conditions causes centrifugal arterial flow from the medullar artery into cortical capillaries, without centripetal flow from the periosteumto the cortex. [12,17] If descendent branches of nutrient artery are cut, according to Bergen, "reverse" - centripetal flow is activated, ensuring adequate vascularization and healing of subperiostal-osteotomized fibula, distally from nutrient artery entrance. [17]

In order to allow adequate blood supply for the bone, periostal branches, formed from muscular branches of peroneal artery should be preserved, taking, on the anterior side, 2-3 mm thick muscular layer of m. tibialis posterior and , on posterior side, taking m. flexor hallucis longus. Such technique ensures both endosteal and periostal graft vascularity.

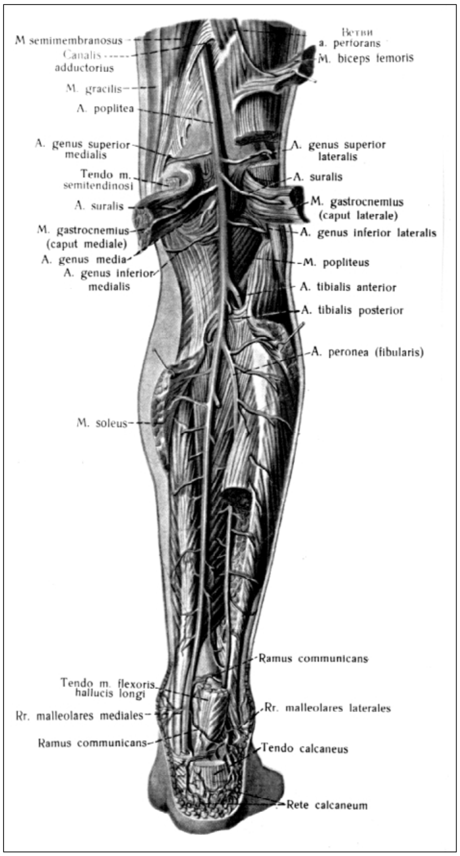
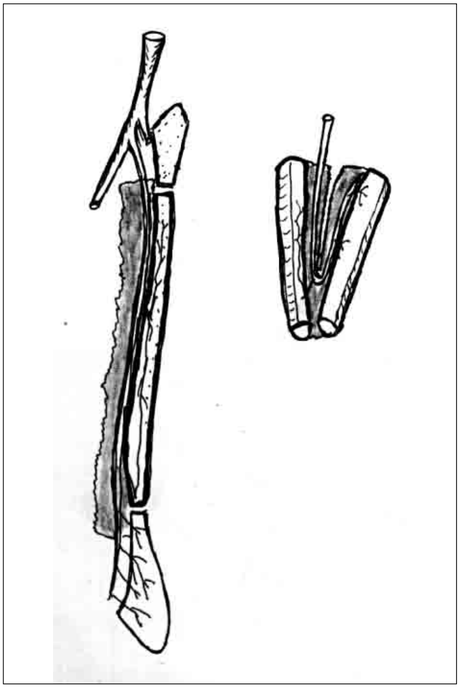


Fig. 1.

Fibula is exposed using Gilbert's lateral approach. Incision line extends from the fibular head to the lateral malleol, then to the subfascial space, entering peroneal septum, or space; anterior to posterior edge of long and short peroneal muscle, and posterior to anterior margin of soleus muscle. [4] Then peroneal artery is identified since it enters supramedial side of fxexor hallucis longus. It should be exposed with veins, all along up to the origin from posterior tibial artery. A. peronea is the strongest branch of a. tibialis posterior , often having the same or greater caliber. N. tibialis crosses artery in the proximal part from the posterior side, passes medially to it and exits between peroneal and posterior tibial artery. Cut is performed on interosseous membrane, leaving intact posterior tibial nerve and detaching fibula from muscles from the front and lateral side, then from the proximal and distal side up to desired length. Care should be taken to include the foramen for the nutrient artery , found 18 - 22 cm from proximal end of fibula. [9,11] The donor site is theen closed with drain.

On the implantation site, graft may be either be fixed with screws into medullar cavity on the long bone ends. In areas where early stability can be achieved or there is a large discrepancy in size between the fibula and the recipient bone, then fibular graft may be modified by an osteotomy anterolaterally, (Sch. 3), just distal to the entry of the nutrient artery. Theproximal part of the graft is supplied by periostal and endosteal blood flow, while the distal part is supplied from the periostal blood vessels alone. These, so-called "double barrels" free grafts are indicated in areas such as pelvic ring , then distal femur and ulna.



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3.3. Free vascularized rib graft

Rib can be used as vascularized free transplant or graft as well. It has two blood supply sources : posterior intercostal artery starting from the internal mammary artery . There is an extensive anastomosis between these two arteries and this should ensure safe blood supply from either end. (4,7) Vascularized rib graft has no extensive application in restoring long bone defects, probably due to potential complication at harvesting, characteristics of diameter and limited amount of the rib graft available .

3.4. Free vascularized graft of distal radius

Segment of distal radius, based on radial artery, can be used a free vascularized graft. The application of such graft is limited. Radial lower arm flap can also be lifted as a fascio-cutaneous flap, including half of circumference of radius, between insertion of m. pronator teres and m. brachioradialis, along with the part of m. flexor pollicis longus and m. pronator quadratus, ensuring vascularization of the bone graft with maximal of 10 cm in length. Free vascular graft of distal radius is used as osteocutaneous graft, advantage is presence of generous radial artery and thus safe anastomosis.

IV - COMPLICATIONS OF THE VASCULARIZED GRAFT

Basically, there are two types of complications related to the vascularized graft :

- complications of the donor site
- complications of the host site

1. COMPLICATIONS OF THE DONOR SITE

Most common complication of donor site is postoperative hematoma. When harvesting vascularized bone graft from the iliac bone, attempts should be made to preserve anterior iliac spine, for good esthetic results. (2,4,7,14) In this region dissection must be carefully performed and lateral cutaneous nerve spared. Lesion of this nerve is clinically manifested with paresthesia of lateral tight in 5 to 20 % of cases. (6,7,14)

When obtaining vascular fibula bone graft, the following could occur:

1. distal edema;
2. reversible paralysis of n. peroneus communis;
3. motor deficit in the lower leg;
4. loss of sensitivity and lack of tolerance to cold;
5. progressive valgus deformation of the lower leg as a consequence of distal radial epiphysis growth disturbance .

Lower leg valgus deformity depends on number of years passed from the final closure of the growth line. It is less probable in children older then 12. It can be prevented by preserving distal third of fibula or by inserting screw as a temporary synostosis between distal tibia and fibula. (7,9,12) Fogdestam prefers fibula defect to be repaired, in particularly in children,; repair is done with periostal strips of tibial periosteum10 mm wide, incorporated into cortical layer of tibia.

2. COMPLICATION OF THE HOST SITE

Venous or arterial thrombosis is the most severe complication of the host site; it occurs in 3 to 5 %. (6,9, 12,14). Stress fractures of vascularized graft occur in 10 to 25 % of cases, regardless iliac crest bone or fibula is used. (5,7,9) Graft fracture is managed in the same fashion as the host bone fracture., and in 5 to 10 % of cases there is a need for bone re-grafting in order to support and facilitate healing and consequently, incorporation of the vascularized graft.

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IV
EXTERNAL FIXATION

1.0. EXTERNAL FIXATION

The external fixation is a device used in orthopedic surgery, war and peace-time trauma, for fixation of bone fragments by wires and pins inserted trough the parts of bones and being fixed for mounting of the external fixator.(1,3,12) This therapeutic method is called external fixation. (Fig.1.)Fragments of the injured bones are stabilized with it and held in a desirable position. By using an external fixator for fixation of bone fragments we obtain neutralization, compression, dynamization, distraction, angulation, rotation, osteotaxis, ligamenotaxis and elastic fixations.(2,5,9)

Neutralization understands maintenance of the limb length and prevention of the shortening. It is performed in comminuted fractures with many small fragments that cannot participate in stabilization and in bone defects.(4,11,17.)

Compression keeps the fragments in direct contact and prevents their movement. Pressured by the external fixator, healing of the fracture is expedited.(4,6)

With mechanism of **dynamization**, axial power from fixator is transmitted to the bone, which enables micromovements on the place of the fracture.

Fig. 1.

Dynamization can be obtained in various ways, depending on the type of fixator and mounting of the frame. Fixators using wires have no need for dynamization.(7)

Distraction of the bone fragments is used on the place of the fracture or after osteotomy and occurrence of gluey calus, in order to achieve desirable length of the injured bone, or to compensate the fragment defect. It is often used in the orthopedic surgery and in bone trauma if the metaphyseal and intra-articular fractures are present.(7,8,9)

Angulation: the frame has in its construction the possibility to correct the limb angulation.(4,6)

Rotation: A possibility of the bone fragments rotation with external fixator exists if the external frame has a universal joint which permits movements in all three planes.(7,8)

Osteotaxis, a term introduced by R. Hoffman, understands reposition of the fracture without opening. (9)

External manipulation, in which reposition is supported by preserved ligaments, is called **ligamentotaxis.** (9)

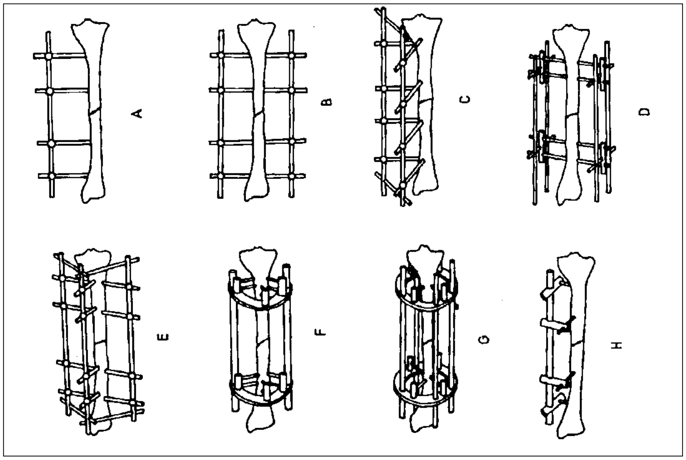
Burny has proved that **elastic fixation**, which enables permanent presence of micromovemnets on the place of fracture is optimal for the bone healing, and this rigidity and elasticity can be obtained by application of the external fixator.(17)

According to the biomechanical, technical possibilities, geometric configuration and ways of application of the frame of the external fixator we differ:(Sch.1)

a) unilateral, b) bilateral, c) V-shaped frame, d) circular, e) triangular, f)semicircular, g) quadrilateral and h) unilateral with convergent pins.

The application of one frame of external fixator in one plane is called unilateral and two frames in one plane bilateral. In fixators where pins are parallel (bilateral), latero-lateral stability is more than optimal, but antero-posterior stability is decreased. The unilateral frame with convergent pins has a good and equal antero-posterior and latero-lateral stability, if an adequate number of pins is placed correctly. (4,7)

The quadrilateral frame consists of two double bilateral frames. Such an application of external fixator provides a good stability in all planes. A closed frame can be circular or semicircular. The circular and semicircular fixators with wires have a good antero-posterior and latero-lateral



Sch.1

stability and dynamization. A permanent elastic compression causes physiological compression of the external fixator, supported with the contraction of limb muscles. To achieve this, a sufficient number of wires must be applied in adequate places and maintain 1cm distance between the skin and frame. [4,7]

Fixators that use pins, in order to be useful have to meet the following criteria: number, grouping and thickness of the pins, place for pin applications and their threads and an adequate distance between the bone fragments and external frame of fixator. Characteristics of these fixators are that the pins should be inserted through the intraseptal spaces of the muscles (groups of muscles) and through the skin and bone fragments. In an application of a bigger number or groups of pins closer to the bone fragments we achieve better stability. With the increase of the distance between bone fragments and external frame stability decreases, and it is needed to place connections at 1cm distance from the skin. [17]

1.1. Indications for external fixation

Indications for external fixation are specific. Each problem should be approached individually, and in order to solve every one of them in the best possible way a surgeon has to be familiar with other conventional methods.

Widely accepted, absolute indications for external fixation are the following:

1-treatment of bone fragments in a war wound caused by firearm

2-fractures II and III according to Gustilo

3-fractures requiring reconstructive surgery of the skin or free vascularized flaps

4-fractures requiring distraction and neutralization of the bone fragments, associated with a significant loss of bone

5-fractures of the long bones of the limbs, where is important to maintain the same length (radius, ulna)

6-fractures combined with burns and loss of skin

7-infected fractures or nonunions

8-arthrodesis

Relative indications are as follows:

1-fractures of the pelvis with dislocation and opened, infected or non healed fractures,

2-fixation of the fragments after radical resection of the tumors, with autologous or heterologous bone grafting,

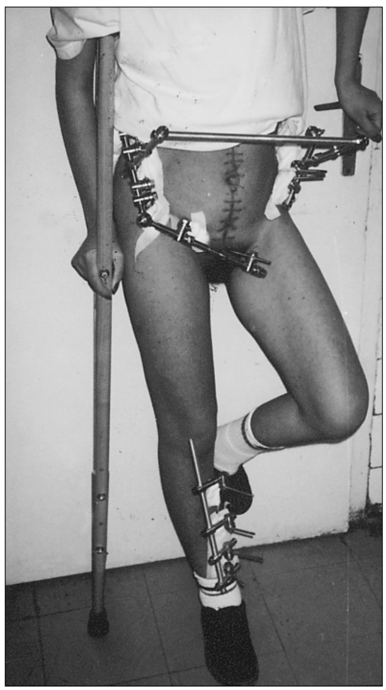


Fig. 2.

3-osteotomy in children; external fixations eliminate the need for the subsequent removal of osteosynthetic implants,

4-fractures to be followed by repair or reconstruction of the vessels and nerves,

5-stabilization of the segments in closed fractures,

6-correction of the congenital deformities,

7-enforced stabilization of the bone fragments, where screws or wires are already placed, but an adequate stabilization is not achieved, [17] 8-ligamentotaxis, in intra-articular comminuted fractures, when by dragging the ligaments and capsular structures, reposition and stabilization of the fragments are achieved. This concept is very convenient in the distal fractures of the radius, although plaster of Paris is mainly used today,

9-stabilization of the fractures in polytraumatized patients who often require transport for the repeated diagnostic tests, (Fig.2.)

10-fractures in the distal third of the lower leg if plaster immobilization is not satisfactory,

11-transpedicular stabilization of the spine in war wound.

1.2. Method of application

The application of an external fixator with pins starts with 1cm skin incision. A smaller incision, when applying a pin, causes twisting and necrosis of the skin, squeezing and additional necrosis of muscles, impairs the continuous filtration of lymph, decreases mobility of the skin (its stretching) thus preventing the full functioning of extremities, causing contractions of the joints. An incision bigger than 1 cm makes the wound open to the infection by air. After the incision, provide access to the bone along the muscle fibres, between muscle groups with a blunt instrument, with step-by-step nontraumatic closing and opening of the hemostatic forceps. A drill sleeve is inserted into the space with a trocar inside. Leaned on the bone, strike the trocar with a hammer to mark place, where the bone will be drilled to avoid sliding of the drill and macerating of the soft tissue. With respect to the pin width, drill the bone with an adequate size of the drill bit. I have been using a drill bit which is 2 mm thinner than the pin. Drilling should be done with a sharp drill at low speed, making pauses to allow the drill to cool. [17]

According to Matthews and Hirsch a great number of rotations of a blunt drill bit causes temperature of 1400 C at 0,5 mm distance from the drilling point. This causes devitalization of the bone, aseptic necrosis, osteolysis, loosening of the pins and increases the risk of infection. Chao proved that high compression to the bone causes necrosis and damage to the bone causes necrosis and damage to the osteocytes. Drill the bone to create a channel where a pin will be applied and irrigate the channel though the sleeve with saline under pressure (syringe). In this way the tiny pieces of necrotic tissue of the bone and clots are removed, and the drilled is cooled off.[2,6,9]

By the time you will gain experience in pin application (front, rear cortex), but if the experience is not so great, it is better to use an instrument to measure the length of the pin that should be applied. The pin is inserted through the sleeve in order to avoid trauma and maceration of the soft tissue which may be interposed between the pin and bone in the channel.

It is not necessary to incise the skin for the application of the fixator which uses wires for stabilization unless a wire with olive is applied. You should chose an adequate size of the wire, with respect to the aim you want to achieve with the fixator. The size of the wire also depends on the place of application and bone structure. [4,7]

Once the fixator is applied, the complete functioning of the injured extremity has to be checked at the operating table.

We check the stability of the fixed bone fragments and incision of the skin around the pins. In the places where the incision is too small or the pin is tightening the skin, the incision is enlarged so that skin is mobile again. If the incisions are too big, place one suture to achieve the adequate size.[8,9]

Being treated in hospital, the patient (as well as the family members) is trained how to perform toilette of the external fixator.10-12 days after the application, gauze is not put around the pins any more. Toilette around the pins is performed 2-3 times every day with antiseptics removing the brownish layer around the pins and preventing crusts. [1,2,7] When discharged, the patient is advised to maintain the same procedure with antiseptic; if not available, alcohol or other solutions are to be used instead. The patient himself can clean the injured extremity and the fixator with neutral means (baby soap) at his bathroom, or in a swimming pool if he is in a rehabilitation centre. The gauze should be removed after twelve days and it is enough to put an appropriate, neatly washed and ironed underwear over the fixator. Gauze around the pins prohibits or reduces permanent flowing of the fluids, and increases the risk of infection. If infection, in spite of all these measures undertaken, occurs around a pin (usually infection occurs around one pin) and a minor infection tends to become a major one, it is necessary to remove the pin. This problem is more difficult to solve when there is a bigger number of pins within a small place. The Mitkovitsh fixator, with great mobility of the mobile connection and pin holder, provides an easy solution to the problem. (2,6,9)

Under the infiltration or general anesthesia a new pin is inserted in order to maintain the same stability. Then the pin around which the infection occurred is removed and the same mobile connection and the pin holder are used for fixation of the new one. (1,2,7)

If a minor infection is not healed in 2-3 days or tends to progress, the pin should be removed before clinical signs of infection appear around the pin.

1.3. Place of application

An orthopedic surgeon who applies an external fixator must have an excellent knowledge of anatomy, relations and cross sections of the extremities, has to know relatively risky and safe areas for application. The segments where a bone lays concentrically have low risk areas of musculo-tendineous units. Relatively risky areas contain neuro-vascular elements. (4,7)

2.0. COMPLICATIONS TO EXTERNAL FIXATION

As every other surgical procedure, external fixation also has its complications. The most frequent one is infection around the pins.(Fig.3.)

The presence of the foreign body in the limb causes the reaction of body which locally creates a membrane in order to expel the foreign body out. A bursa will be created if there are movements between the local tissue and foreign body. Placing the pins of the external fixator, a continuous lymphatic drainage is established, which means if outflow is possible, there is no reason for infection. Reasons for the infection are the following:

a) closure of the space around the pin by an inadequate, small incision,

b) great mobility of the soft tissue,

c) incision bigger than 1 cm, which allows infection to spread by air, with its expansion along the pin towards the bone,

d) "brutal" work on soft tissue and bones during the application of the pin,

e) inadequate wound care.

In 1981, Green introduced the terms "minor" and "major" infection, occurring around pins. The minor infection is an increased secretion around the pin, and the major infection is causing redness of the skin around the pin, pain and suppuration, which presents a serious problem. (4,7)

Problem is even more serious if the pin affected by infection is placed in the epiphysis or the metaphysis, where spreading of the infection through cancellous bone increases the possibility of pathological fractures and intraarticular infection.

Fig. 3.

Application of the external fixator requires certain steps in order to prevent the infection. The choice of the fixator is very important, its biomechanical characteristics, arrangements of the pins, and possibility of easy regrouping of the pins in the course of treatment if needed should be taken into consideration. (2,6,9)

With fixators, where a big number of pins is grouped within a small space and in one plane, the possibility of infection increases. It is an interesting to mention that the number of infections is greater when the external fixator has many components which have to be connected during the application. In the Association for Material Testing in USA, various fixators made of Titanium, different kinds of stainless steel, cobalt alloys were continuously immersed in salt solutions (sea water) for 4-5 years. There were no visible changes at all on these alloys. (4,7)

2.1. Vascular injuries

It is believed that blood vessels may be initially severely damaged either by a drill bit or a pin. Most frequently it is the anterior tibial artery and rarely the femoral artery. (1,2,7)

I had a complication in my work - an injury of the femoral artery which dramatically appeared after the latent period of 12 hours after the application of the fixator. Intraoperatively an iatrogenic lesion of the tunica adventitia was discovered. The tunica interna ruptured, most probably, after the postoperative normalization of the intraluminal tension, causing the delayed clinical presentation. (2,6,9)

2.2. Lesions of nerves

Using a unilateral fixator, a nerve can rarely be damaged. Injuries are more frequent with application of the bilateral and quardilateral frame. The nerves most commonly damaged are the radial nerve in the distal half of the upper arm, as well as the deep and superfacial peroneal nerves. Fixators with wires are more dangerous since there is a risk of puncturing the nerve.(11,15,18)

2.3. Delayed healing

In order to prevent slow healing compared to other conventional methods, a regular radiological follow-up is necessary. Forming of the bone callus is evident on the X-ray 2-3 weeks after the application of the fixator. The radiograph serves as a guideline to what is to be done on the frame of the external fixator in order to speed up healing of the injured bone. The action provided with the frame is to stimulate the following: 1-dynamization, 2-biocompression, 3-elastic fixation, 4-rigid fixation and 5-correction of the angulation. When the external fixator is removed, a rational plaster of Paris or orthosis for 14-21 days is highly recommended to:

a-prevent complications if the patient does not cooperate

b-avoid wrong estimations of the bone callus; in oblique, spiral or comminuted fractures superposition of callus and fragments tend to appear,

c-make the softened callus rigid and avoid the angulation and abbreviation of the extremity. (1,2,7)

2.4. Contractures and limited function of the joint with external fixation

Fig. 4.

If pins are applied through the muscle, that is, a big number of pins through the groups of muscles in the same plane, there is a great risk for the joint contracture. This complication is more prevalent with the application of bilateral, quardilateral or triangular frame. With such an application the pins have to pass through the same muscle groups. The contractures can be prevented either by a unilateral fixator with convergent pins or by designing a V-shaped frame and placing most of the pins into intermuscular spaces or in the foot, making a special sole of proper material or plaster. (Fig.4.)

Contractures of the knee and ankle are most commonly described in peace-time traumas, while in war traumas all joints of the extremities may be involved. An adequate stabilization of the bone fragments is necessary and must be done as efficiently as in some other conventional methods(AO method, Küntscher…) Such a stabilization provides an early rehabilitation, already on the third day, walking on shoulder crutches, supporting and relieving of the joint. [11,15,18]

2.5. External fixation and amputation

In war surgery amputations of the upper and lower extremities at all levels are very common. Amputation can be associated with proximal injuries of the extremity. (Fig.5)

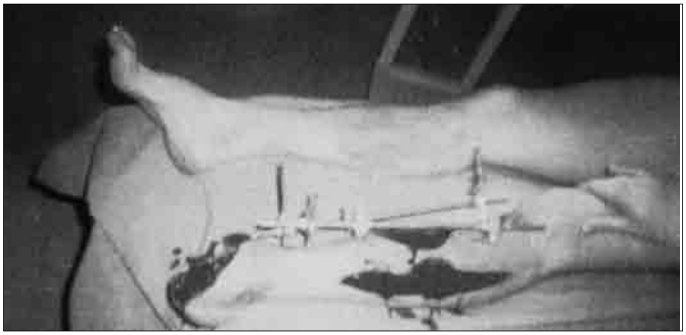


Fig. 5.

Among the injured there are many young people who are expected to provide years of active life yet; therefore it is necessary to preserve the amputated extremity as long as possible. It is needed for the following reasons: better prosthesis, better function of the amputated extremity and fewer complications. [11,15,18]

Nonviable tissue and damaged soft tissue are first to be cut followed by the cutting of the bone as distally as possible. The remaining viable tissue should be able to cover the bone, without unnecessary abbreviation of the bone when the delayed suture is performed. Leave an intact muscle open, because it swells less, better preserves the sutures and is more suitable for coverage of the amputated extremity. Then, the best solution is to perform themyoplastic amputation which is using the entire muscle: the gastrocnemius, media head of gastrocnemius muscle, soleus and vastus medialis, depending on the place of amputation. [1,2,7]

When the amputation is completed, check the haemostasis, make the primary surgical treatment of the proximal part of amputated extremity and stabilize the bone fragments. [4,7]

Is it better to amputate and then perform the proximal stabilization? Each case is individual and the decision is made at the operating table.

3.0. MITKOVITSH FIXATOR – M 20

This fixator designed in 1991 by Dr Milorad Mitkovitsh from Nis, is one of the fixators which gets closest to the biological laws of the bone, and it has been mostly used in The Republic of Srpska during the war (over 4000 external fixators for treatment of the war wounds of extremities). [4,7]

This unilateral type of fixator has the following characteristics: frame length is 320 mm, it has 4 mobile connections of 60 mm in length, with 4 pins 150 mm long, and weighing 650g (Fig .6.).

With this fixator an adequate bone stabilization is achieved. Since the mobile connection and pins are very mobile, the most optimal way is to apply the pins at convergent angle of 900 - frame, mobile connection, pin, bone. The distance between the mobile connection and bone should be reduced to the minimum. Thus a balanced stability is achieved in antero-posterior and latero-lateral directions. Axial micromovements are minimal which allows healing of the fracture. Pins applied in such an order contribute to osteogenic reaction of periosteum at the point which is distant from the fracture. In this way the periosteal reaction is generalized, osteogenic process is greater. Try to apply the pins 40 mm from each other. [4,7]

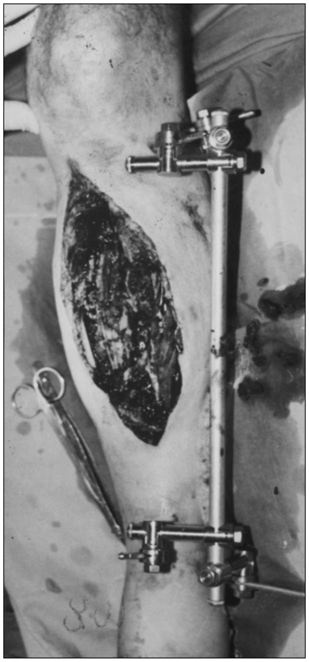


Fig. 6.

This fixator is simple, easy for application and of satisfactory weight and design. It is a

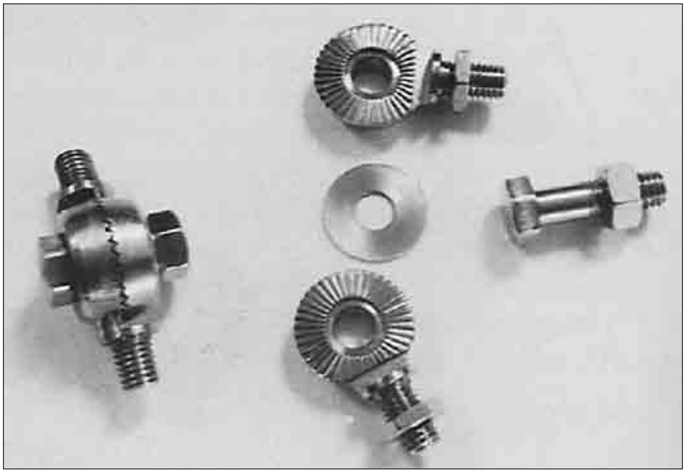


Fig. 7.

high technology product and can be used several times. It is cheap in comparison to the other ones. Only one wrench is needed for the application. Using the fixator in some specific circumstances I was putting additional parts which made it even more useful in treatment of complicated fractures. I have designed an articulated tension device which can be mounted on the frame or on the mobile connection of the fixator.(Fig.7.8.)

Fig. 8.

The mobile tension device is made in the shape of two half balls with threads of 10 degrees which enable the rigid stability, joint distension and unlocked becomes a hinged joint maintaining the stabilization of the bone fragments in an early mobilization. The articulated tension device enables construction of the semicircles and frames. The correction with this device is possible in all three planes. (1,2,7) Blocking the connection in a desirable position, angulation can be corrected since each thread can correct it for degrees, while the correction in the needed plane is possible with deblocking. Bearing in mind that the Mitkovitsh fixator should be a part of the military equipment, the connection which turns this fixator into a cold defensive weapon such as dagger, spear, was added on the frame (Fig.9.)

First aid to the wounded should be given on the spot by his fellow combatant. The fixators of both the wounded and his fellow combatant make an excellent means for the immobilization of the injured limb. (11,15,18) There is no Kramer's splints on the front line nor is there time and possibility to make one of wood or any other material.(Fig.10.)

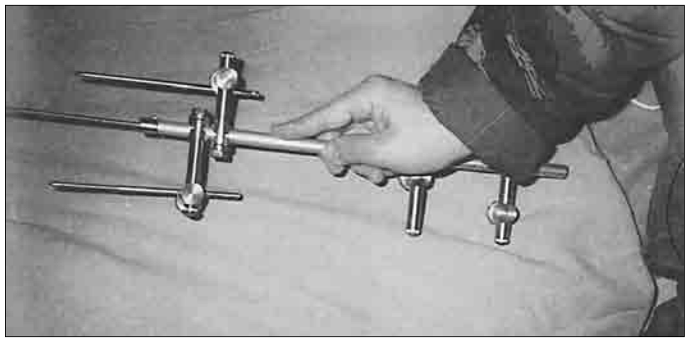


Fig. 9.

Fig. 10.

Eight Mitkovitsh fixators together with the articulated tension device make excellent stretchers which can be either carried or dragged. Upon the arrival at the surgical unit the same fixator can be sterilized and used for the stabilization of the injured fragments of the limb during the primary treatment of the wound. In surgical units there is usually no Crutchfield traction but it can be more than satisfactorily replaced by the Mitkovitsh fixator (Fig.11.).

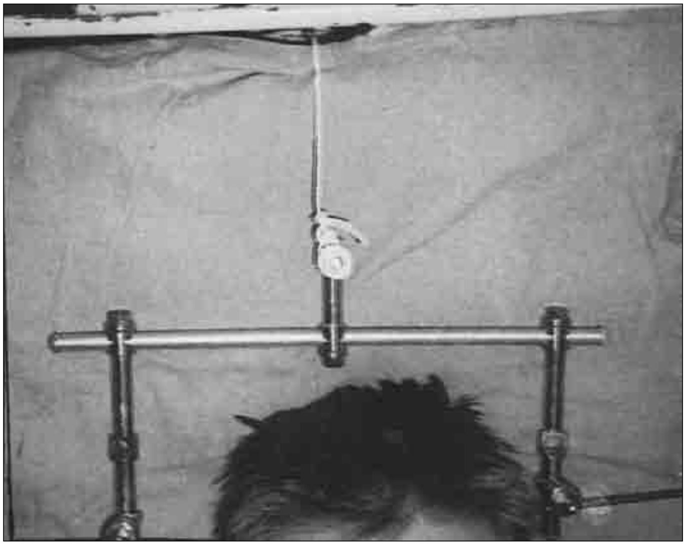


Fig. 11.

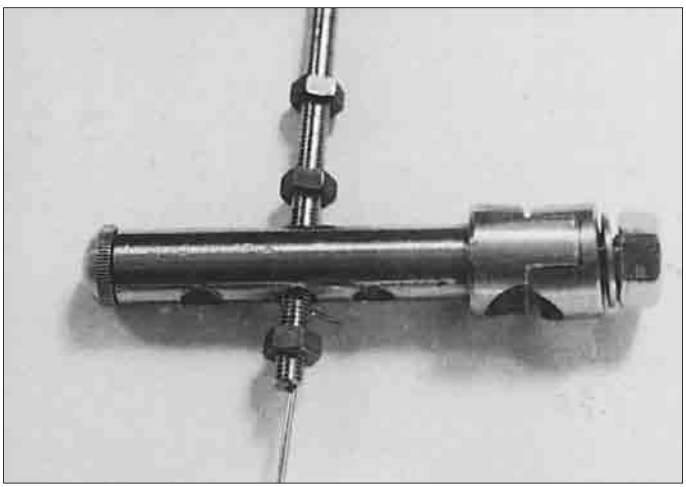


Fig. 12

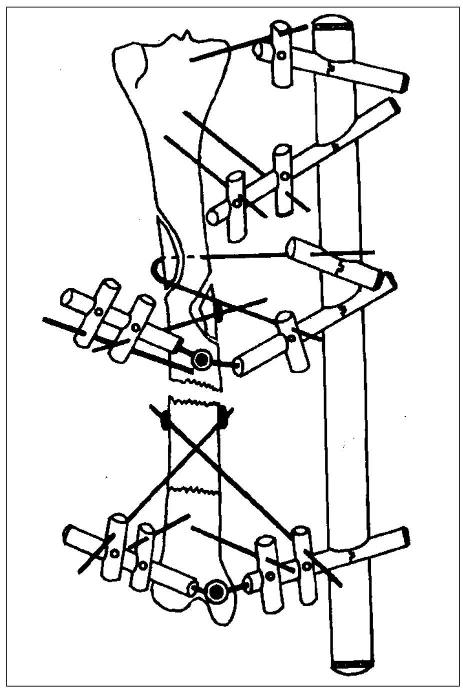
Providing the mobile connections and frame with holes (Fig.11) it is possible to apply Kirschner wires and to use the method of banded wires for the transversal compression for the monolocal and bilocal compression. It has been shown that working in this manner, a separate construction for a case is required.(Fig.12)

Thus, different, more universal solutions have been revealed. It is possible to make a holder for Kirschner wire from a pin, which is tightened by a mobile connection and a holder for fixation of Kirschner wire. [11,15,18] A great mobility of the connection and of the pin tension device provides a universal application for Kirschner wire wherever indicated.[9,11,15]

Mounting the 4mm telescopic frame (Sch 2) in the places where a pin, mobile connection and a pin holder of great mobility are applied enables the monolocal and bilocal use of this fixator for the bone distraction.

The use of this unilateral frame as a bilateral, triangular or with an articulated tension device as semicircular (Fig.13,Sch 3) is rarely required. [9,11,15] Following the experience with the Mitkovitsh fixator we have designed a "mini" Mitkovitsh fixator for the hand and foot traumas of the following dimensions: the length of the rod - 80mm, mobile connection- 20mm, four pins 50 mm - long and 2 mm- wide, with an appropriate articulated tension device.

There are broad indications for the usage of Mit-



Sch. 2.

kovitsh fixator in war wounds, in piecetime trauma and in orthopedic surgery, as to be discussed in the following chapters. [12,15,18]

3.1. Stabilization of the bone fragments in war wounds

Even after the best wound management you cannot use the classical surgical procedures for stabilization (Fig.14.).

I recommend that you under visual control reduce the bone fragments through the existing wound hole, which can be extended, if necessary. Incise the skin and place the first pin through a drill sleeve, up to the non-damaged fragment, at least 3cm from the fracture. Pin should be placed in the metaphysis and epiphysis without pre-drilling. Penetrate the cortex, punching the pin with a hammer and the pin will thread its own way through the cancellous bone. Placed like this, the pin will be more stable. [9,11,15] If the first pin is placed in the distal fragment, the second one should be placed in the proximal fragment. When a frame is applied and these two pins fixed, if needed using a reduction forceps, continue to place pins distally and proximally until full stabilization is achieved. [1,2,7]

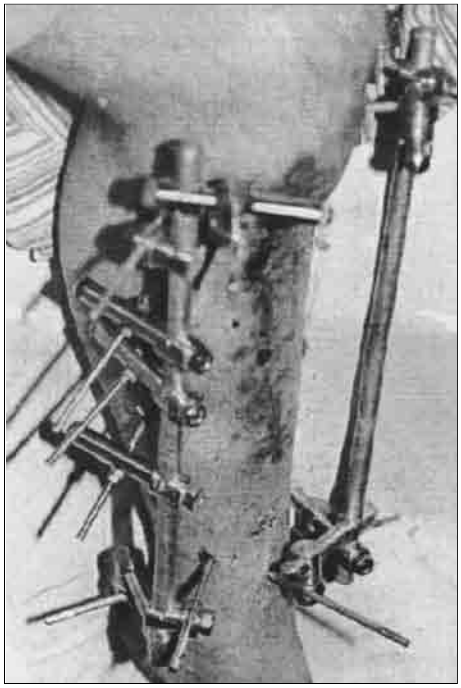
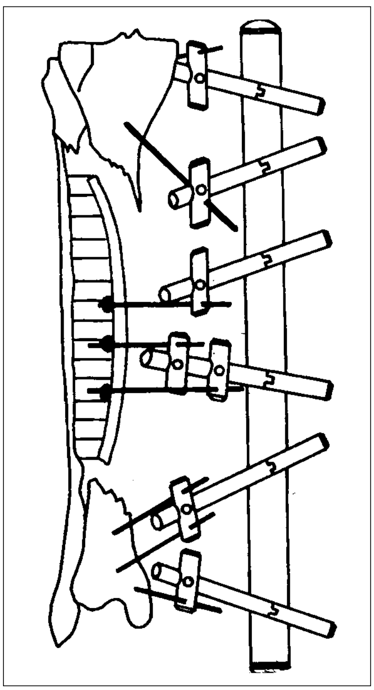


Fig. 13.

3.2. Treatment of war wounds of the humerus with the Mitkovitsh fixator

The shoulder, which is one of the last joints in the phylogenic evolution, has developed into one of the most mobile joints, with the possibilities for extensive coordinated motions. The great mobility is due to the incongruity of the joint surfaces, the relation convex - concave is 2:1 or 3:1, depending on whether the longer or shorter diameter is observed. [8,9] The joint has an extensive capsule, and the humerus does not articulate with a fixed bone, but with the mobile scapula. The significant motions of the scapula start after 450 of the shoulder abduction and anteflexion of 600. The physiological angle between the humeral head and shaft is 1350-1400, with variation of 250, retroversion of the humeral head is 200-300. Variations of these angles are big, therefore compressive, comminuted fractures do not require anatomical reduction. The mobility of the shoulder joint is a result of the synchronized action of the following muscles: the deltoid muscle, rotators of the cuff,



Sch. 3.

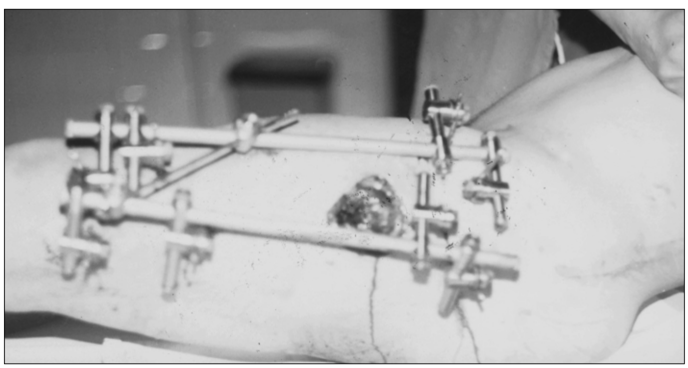


Fig. 14.

(subscapularis muscle, supraspinatus muscle, infraspinatus muscle, teres minor muscle). This hanging joint has the function to bring the arm and hand to the best position for the daily activities. Having all advantages for such a role it has the following disadvantages: an increased inherit sensibility to peace-time injuries and especially to war trauma. [9,11,15]

War wounds of the shoulder are characterized by an extensive bleeding. Very often the anterior and posterior humeral circumflex anteries are injured. Usually there are extensive distractions, defects of the muscle, capsule and skin. Fractures of the humerus have more fragmentes with dislocation. Injuries are often so big that lead to semiamputation of the upper arm. Such injuries can be combined with abdominal, thoracic and craniocerebral injuries. Stabilization of the proximal humerus fragments is obtained by the following procedure: two pins are applied in the humeral head and two in the shaft, depending on the soft tissue damage and fixator weight. On the first radiography check-up, even after 3-4 weeks, subluxation or luxation of the humeral head is visible. (Fig .15.)

Then the problems arise – what to do: the fracture is not healed, the fixator weight and muscle defects will lead from subluxation to luxation, the glenoid cavity is filling with connective tissue, which leads to degenerative change of the shoulder joint cartilage and capsule. Prevention of this unnecessary complication is very simple - place a pin into the acromion or the scapular spine.(Fig 16.17,18.)

The choice of where to place the pin will depend on the defect of muscle and skin, easier approach to the wound or the need for reconstruction. Application of the pin is simple; both processes are palpable under the skin.

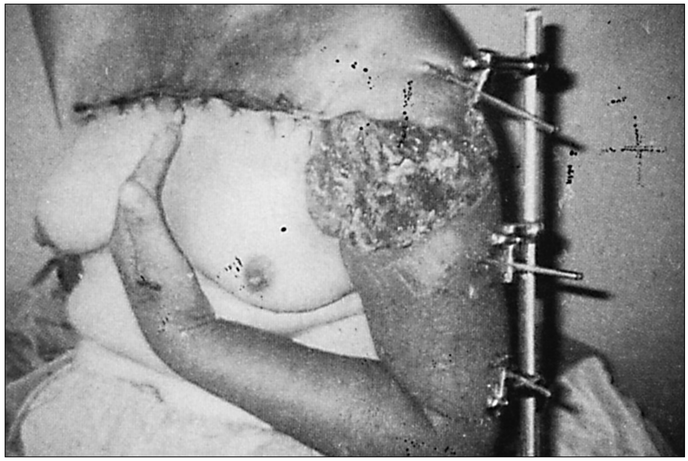


Fig. 16.

Fig. 15.

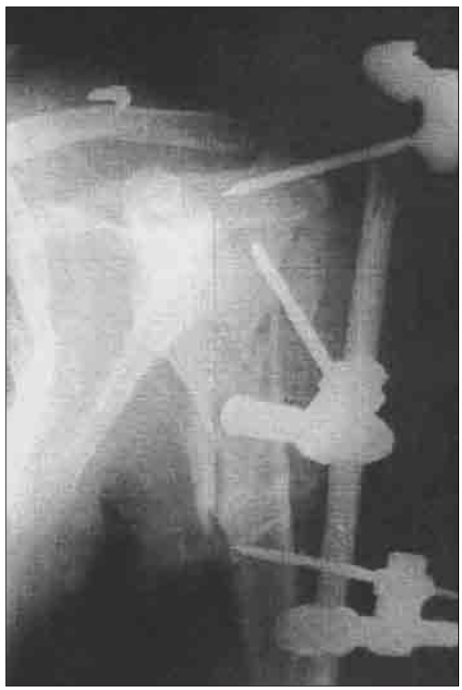


Fig. 17.

After the skin has been incised, use a bone drill only to penetrate the cortex and apply the pin. The pins of the acromion of the spine of scapula should be the first ones to be removed after 3-4 weeks. [1,2,7]

Stabilization of the proximal humeral fragments in such a pattern enables small circumscriptive mo-

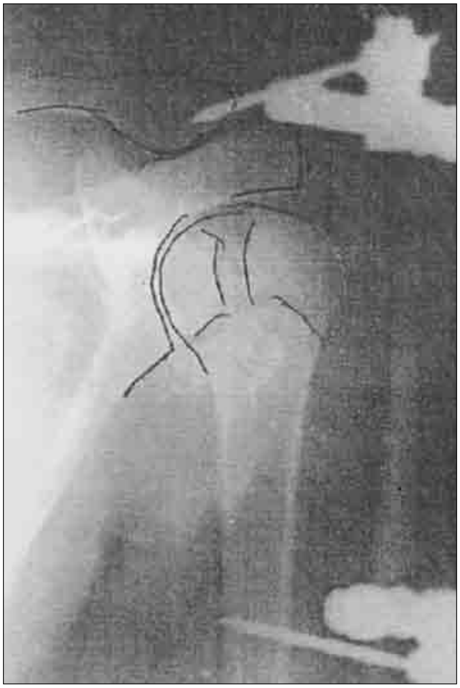


Fig. 18.

tions of the shoulder joint and prevents its subluxations and luxations. If the war injury of the proximal humerus is combined with luxation of the acromio-clavicular joint, one pin should be placed into the clavicule and reduction and fixation of the joint performed. It is enough to use four pins for stabilization of the humeral fragments; in segmental humeral fractures it is necessary to place additional pins, meaning that 2 pins should be placed in each bone segment. Place the pins into interseptal spaces of a muscle or groups of muscles. (12,15,18)

3.3. The elbow

Made of three bones, in anatomical sense, the elbow joint is a complex joint. It is made of three joints: humero-ulnar joint, which functions as one. It forms the mechanical connection between the upper arm and forearm, enabling the hand, together with the scapular function, to make the needed spatial positions. This function is provided in the humero-ulnar and proximal radio-ulnar joint (flexion and extension), while supination and pronation are provided in the proximal and distal radio-ulnar joint. The centre of the humeral trochlea and trochlear incisura is in front of the humeral and ulnar axis, so there is no contact between ulnar coronoid process and humerus, which enables 1400 flexion. Humeral trochlea provides orientation of the forearm towards the upper arm and the angle between them in flexion and extension. Processes on the skin of the elbow (both epicondyles, olecranon and in full extension, radial capitulum) serve for the orientation for percutaneous fixation. In full extension both epicondyles and olecranon are in one plane forming Hueter line; in 900 defection these processes form an isosceles triangle. (12,15,18)

War wounds of the elbow can be extra-articular or intra-articular, often with nerve injuries. To obtain good functional result, it is necessary to fulfil three basic conditions:

· anatomical reduction,

· rigid osteosynthesis,

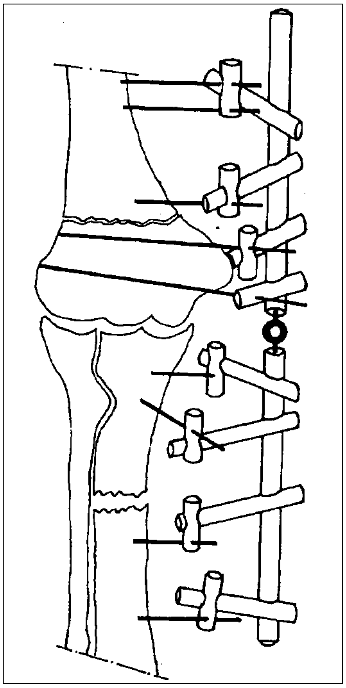
· early mobilization of the elbow and physical therapy.

Stabilization of the extra-articular fractures (supracondylar) with the Mitkovitsh fixator is obtained in the following fashion: after incision of the skin and drilling (cortex only), insert one pin at the epicondylar level. The pin, by selfthreading through the cancellous bone, can be placed in a desirable position. The second pin should be inserted into the distal humerus, tending to be placed convergently with the pin interspace of 1cm. (1,2,7)

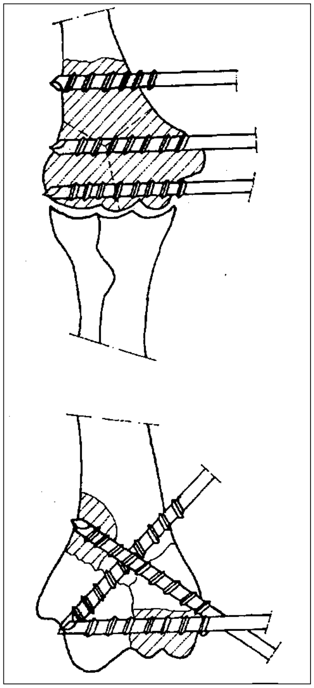
Intra-articular fractures of the elbow joint:

If it is not possible to insert more than one pin into the distal humerus, use the articulated tension device placed in the elbow axis. Once deblocked, the elbow becomes a hinged joint, maintains the stability and neutrality of the fragment with gradual and controlled bending (flexion-extension), which means equal burdening and disburdening of the joint. Put the mobile connection distally on the joint tension device and two pins into ulna. If the supracondylar fracture of the humerus is combined with the ulnar fracture (transversal, comminuted, segmental), the ulna is stabilized by assembling the frame, distally, on the articulated tension device.(Sch.4,5.)

In intra-articular injuries of the distal humerus, transform the multifragmental fracture into less fragmental, stabilize temporarily with Kirschner wires and reduction forceps, then stabilize the fragments with pins. (12,15,18)



Sch. 4.



Sch. 5.

3.4. The forearm

To treat war wound in the forearm, with or without defect of the radius and ulna, calls for a good knowledge of the functional and pathological anatomy of the forearm. Functioning of the elbow joint and wrist must be provided for in treatment of the forearm. The wrist consists of five smaller joints: radio-carpal, medio-carpal, capro-metacapral, capro-metacarpal-pollicis and pisiform bone joint. [9,11,15] All these joints are necessary for proper functioning of the hand, but the most important ones are the radio-carpal and medio-carpal joints. There is a special axis around each of the two joints, which enables the volar and dorsal flexion, and is of primary importance for the hand functioning. This is something that has to be kept in mind while treating an injury of distal radius.[1,2,7] An inadequate stabilization of bone fragments of the radius or the ulna will result in angulation, shotrening of one or both bones and endangering the function of the elbow or hand, or lead to prosupination of the forearm. Both injuries of the radius as well as ulna should be stabilized and neutralization of the fragments preserved by two unilateral Mitkovitsh fixators in order to maintain the Böchler`s angle in the radiocarpal joint. An adequate stabilization, neutralization of the fragments, early mobility of the elbow and hand, as well as supination and pronation (Fig. 19) are achived by application of the external fixators.

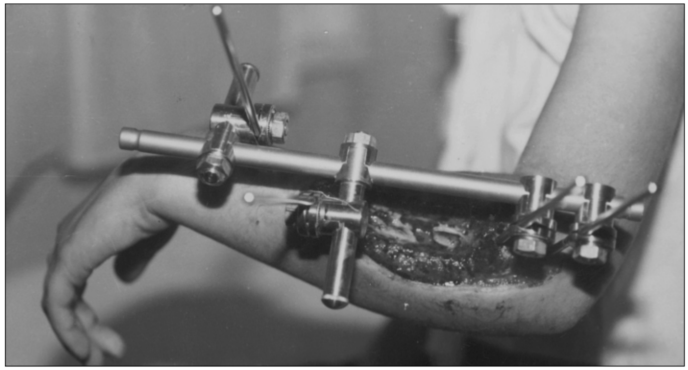


Fig. 19.

Fig. 20.

Typical radial fractures, as the anterior and posterior distal radial fractures, should be stabilized with the fixator in the following way: two pins in the radius, plus two in II and III metacarpal bones. (Fig.20.) A hinged joint can also be applied, with the axis of the joint in correlation with the axis of the radiocarpal joint.

By application of an external fixator the fragments are kept in desirable position and Böchler angle is preserved. The stabilization is more difficult when a plaster cast is applied, and there is a great possibility that the fragments may side.

3.5. The hand

The hand, as an executive instrument of the brain, is at the same time the greatest achievement of the human locomotor system, since it enables the humans a special status among living creatures. As such, it is of extraordinary importance for treating war wounds and other wounds. War wounds of the hand, metacarpus and phalanxes are usually serious, accompanied by injuries and the defects of bone tissue, skin, muscles and neurovascular elements .(Fig. 21. 22.)

In hand traumas a neutralization of injured metacarpal bones and phalanxes must be maintained for further reconstructive procedure. Stabilization can be maintained – performed by Kirschner wires, and neutralization by fixing through the metaphysis of the non-injured metacarpal bone.

Fig. 21.

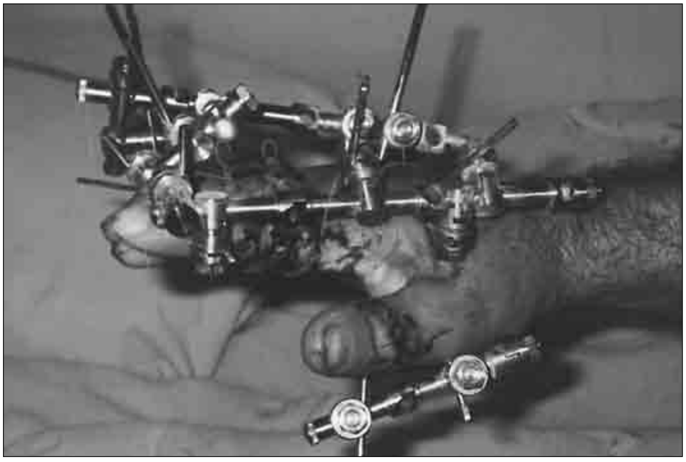


Fig. 22.

This non-stable fixation must be immobilized by the means of plaster of Paris, which is not comfortable, and the plaster gets quickly soaked with blood and septic material. [1,2,7]

The Mitkovitsh fixator of 80mm frame, four 20mm connections and four 50mm pins, together with the articulated tension device is more convenient than plastering.

Application is easy, with great possibilities of constructing. Stability and neutralization are achieved as the axis of the mobile connection is placed in the axis of the injured joint. Deblocked, it becomes a hinged joint enabling a quick mobility of the joint. [12,15,18]

3.6. The pelvis

The pelvis is made of two innominate bones (each consisting of ileum, ischium, pubis), plus sacrum and coccyx. The static burdening is biggest in the sacroiliac region, so care should always be taken in the injuries of the sarcoiliac joints. In pelvic injuries joint fractures do not occur as a rule, just a strain, with rupture of the capsule and the dislocation of articular surface of the joint. The development of the ligaments and muscle system of the lumbosacral region as well as the sacroiliac part of the pelvis in the human body points to the fact that with the usual static burdening the dynamic exertion in the functioning in that part of the pelvis is heavy. [9,11,15] Strong posterior sarcoiliac ligaments maintain the relation of the lateral border of the sacrum and ischial spine, preventing the functioning of rotation and caudal forces. Should there be any fractures and dislocations in one part of the ring, fractures in the other part of the ring are common. Many classifications of the pelvic fracture exist, but the most accepted one is Marvin Tilezs:

(stable)

TYPE A

A-1 pelvic fractures, but no ring fractures

A-2 stable, minimally dislocated ring fractures

(rotationally unstable, vertically stable)

TYPE B

B-1 open book injury

B-2 lateral pressure - ipsilateral

B-3 lateral pressure - contralateral (bucket handle)

(rotationally and vertically unstable fractures)

TYPE C

C-1 unilateral

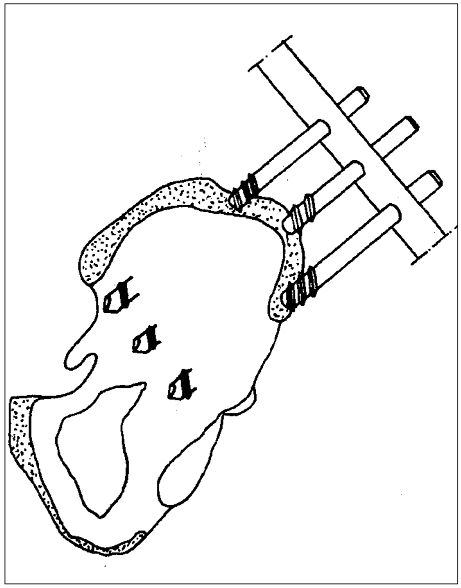
C-2 bilateral

C-3 associated with acetabular fractures

War wounds of the pelvis are severe and often incompatible with life. Several vital organs get injured: rectum, bladder, main blood vessels. [1,2,7] Treatment of such wounds requires a team work, involving surgical teams of multiple specialists.(Fig. 23.)

Stabilization of the pelvis with the Mitkovitsh fixator is simple; a quick construction and 2 to 3 frames is possible. On the two mobile connections it is possible to insert four pins, while constructing of the mobile connection and articulated tension device enables the application of the necessary number of pins for stabilization, for any person, regardless of his weight or height. The pins should be inserted from the lateral iliac side so that they can go (2 - 3 m m - deep) through the cortex in the lower third of the iliac fossa, from the medial side under the iliac muscle. (Sch.6.)

Fig. 23.



Sch. 6.

The iliac muscle is in the iliac fossa, therefore its lesions are rare. The pin will not loosen in this fashion and has a doubled effect, is more stable, thus making easier the reposition of the fragments and mobility of the patient. By constructing the mobile connections, frames and articulated tension device, a bilateral and, if neded, a trilateral frame can be made, taking no account of the height and weight of the wounded.[1,2,7]

The possibilities of assembling and mounting are greater than on the Slatis frame. [8,9] Not even in peacetime trauma are there clear indications for conservative or surgical treatment for the pelvic stabilization with external fixator. By applying the external fixator, the pelvis can be stabilized in:

1) Vertical fractures and rotationally unstable fractures,

2) Instable fractures of the pelvic ring where the need for urgent treatment of bleeding and of vital and traumatized organs,

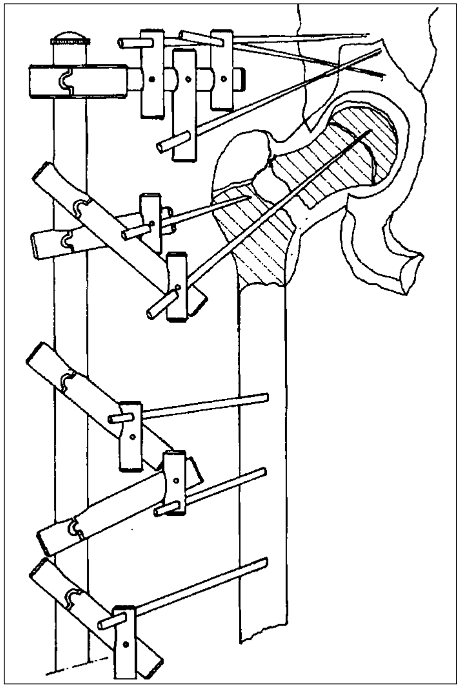
3) Patients whose conservative treatment has to be stopped (because of other complications)

4) Local skin infection

5) Impossibility for pelvic stabilization with the AO method.

The external fixation itself requires the minimal tissue trauma and the surgical procedure is short, but the patient has to be provided with a catheter to prevent his urethra from incarceration in symphysis during the reduction. [4,6,9]

3.7. The hip


Sch. 7.

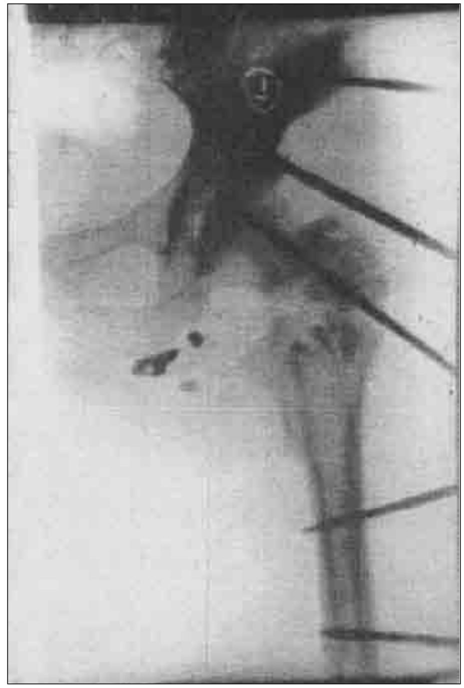


Fig. 24.

The proximal femur consists of the head, neck, greater and lesser trochanter. The neck is 35-50 mm long, positioned anterio-medially towards the shaft, opposite to the greater trochanter. It is wider in its base and gets narrowed in the antero-posterior part. The intertrochanteric line, to which the capsule of the joint is attached on the anterior side, is positioned at the border with the femoral shaft. The greater trochanter, positioned at the proximal end of the shaft, is palpable under the skin and represents an important orientation point when pins are percutaneously applied into proximal femur. Under the skin, from the external side, the most protruding part of the greater trochanter projects medially through the Werd triangle and under the primary tensile and compressive trabeculas, into the femoral head centre. [9,11,15] The lesser trochanter represents the postero-medial protrusion where the shaft changes into femoral neck. On the posterior side continues the introchanteric crest connecting the greater and the lesser trochanter. The femoral head ascends from the femoral neck and is made of two thirds of the ball and covered with joint cartilage being thicker towards the margin. The cartilage in the hip joint transmits and absorbs force while the lubricating liquid minimizes the friction. he fovea capitis in the femoral head is the attachment point of the ligamentum teres which incorporates ligamentum teres artery involved in nutrition of the femoral head. The acetabulum, a strong and big bone mass formed by the iliac and ischial bones, transfers the body weight to the lower limb. Joint contact is only partial and made by the concave, moon shaped facies lunatum, which embraces the acetabular fossa with the attachment point for the ligamentum teres.[3,8,9]

Pauwels, Evans, Böchler and Garden,s classification of the peace-time trauma, based on the anatomical relations of the proximal femur, cannot often be applied in war wounds. In war wounds there is much bigger effect of the kinetic energy which produces greater destruction of the bones and muscles, more often with neuro-vascular injuries. These injuries endanger vascularization of the femoral head by damaging lateral circumflex femoral artery. In war wounds, fractures(medial, transcervical, basucervical) at the femoral neck level are severe and their healing is uncertain.(Sch.7. Fig.24.)

In the beginning of the war I have treated such injures with a direct skeletal supracondylar traction in six weeks' period. [3,8,9] Such a treatment has shown certain disadvantages:

1) It is not comfortable for the injured,

2) Approach to the wound and its toilette is difficult,

3) A young patient is often bed-ridden and dependable on others in basic daily needs for a long time,

4) Increased possibility of complications to bed recumbency (pneumonia, bed sore, skin infection),

5) Long occupation of the hospital bed, prolonged healing and uncertain final result.

These inconveniences can be avoided 10-15 minutes after the primary wound management use to place the Mitkovitsh fixator; e.g. in war wounds, I perform the stabilization of the bone fragments at the femoral neck region in the following way: I apply three pins cranially, in the acetabular mass, and three convergent pins in the femoral diaphysis with the leg abducted of 100-200. In basocervical fractures, add one pin to keep the rest of the neck and head in valgus and anteversion. [3,8,9] The stabilization of the framents in such a way eliminates the disadvantages of the skeletal traction, enables an early mobility of the patient, maintains the neutralization of the extremity and makes walking, without leaning on the leg possible.

Three months after injuring, depending on the union or nonunion of bone fragments, biological operations, such as aloarthroplasty of the hip or bone consolidation procedures, can be in contemplation. [3,8,9]

War wounds of the intertrochanteric region are unstable, with comminution and dislocation of the fragments. After the primary wound management, stabilization of the fragments is done with the Mitkovitsh fixator in the following fashion: two pins are percutaneously applied into femoral neck and three convergent pins into the femoral diaphysis. If stabilization of the fragments is not complete because of the comminution, two pins should be applied into the acetabulum. [4,6,9]

The pins are only to be removed from the acetabulum when X-ray shows signs of bone consolidation.

3.7.1. Epiphysiolysis of the femoral head

Sliding of the femoral head (Fig 25), backwards and downwards, is the basic pathological occurrence in adolescence, most often in the epiphysiolysis of the hip. [3,8,9] The etiopathogenesis is not clearly defined yet, although there are several theories made about it: mechanical, genetical, endocrine, metabolical, vascular etc. The fact remains that the deformation, pain in the hip, limited mobility and antalgic walk occur in the epiphisiolysis and a patient comes seeking medical treatment. There are several methods and ways of treatment.

The most accepted method of chronic epiphysiolisis treatment nowadays is Soutwick's; this is not an every day surgical procedure to perform, particularly in smaller orthopedic hospital, and sometimes a surgeon postoperatively sees that the 50-150 correction would give better results. After the AP X-rays of the pelvis and both hips in the Lauensten position, we determine the angle of correction in anteroposterior plane and the angle of retroversion (Lauensten,s X-ray), which are compared with the intact hip. This

Fig. 25.

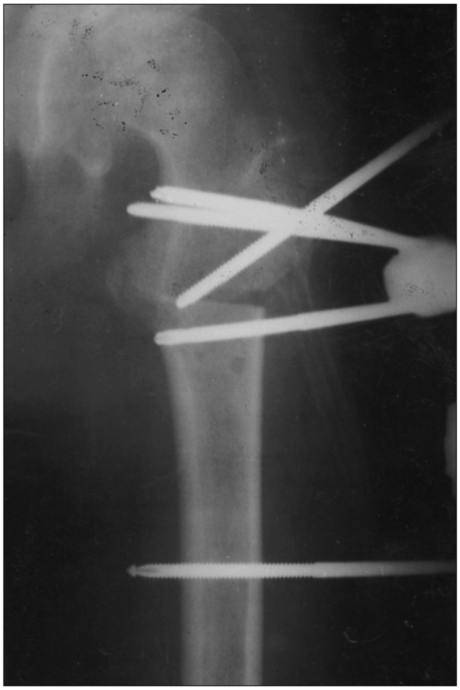


Fig. 26.

will mark the wedge which needs to be dissected in order to correct the deformity, following the dissection of the satisfactorily obtained correction (Fig.26.).

I have no experience in performing stabilization with Soutwick fixator, but the photography shows that it is unilateral frame of lesser mobility. Stabilization can be reinforced with plaster of Paris, but many authors think that the plaster immobilization causes a great deal of chondrolysis.

Stabilization with the AO plate needs additional work, adaptation of the AO plate during the opertion, extended removal of the femoral periosteum necessary for the applying of the AO plate, as well as the traumatizing of the soft tissue. Due to uncertainty in adequacy of osteotomy, inadequate X-ray imaging, lack of patient's cooperation, inexperience of the X-ray technician, nonuse of the mobile X-ray machine during the surgery, the surgeon has to open the joint to see the correction; all this unnecessarily prolongs the surgical procedure and increases the possibility of iatrogenic complications. An additional surgery needs to be performed in order to remove the AO plate after the consolidation of the osteotomy.

Fig. 27.

All this can be avoided by using the Mitkovitsh fixator and the articulated tension device in the following way: the place for the osteotomy is exposed by the minimal removing of the periosteum and minimal traumatizing of the soft tissues only for the size of the triangle needing dissection. After two pins have been applied, the bone triangle is dissected, then repositioned and fixed with two pins. [3,8,9]

Articulated tension device should be preoperatively placed at the angle of retroversion. The fragments are stabilized subsequently, distally and proximally. An early mobility of the patient can be achived, therefore there is no need for additional plaster of Paris immobilization. In comparison to an AO plate, such a stabilization enables the postoperative correction in patient's bed, if the radiography check-up shows that 50-100 correction would be a better sollution. An additional surgical procedure for the removal of the osteosynthetic material is not needed.(Fig.27.) The pins should be removed gradually after the X-ray control of consolidation of the osteotomy. A disadvantage of the stabilization is a delayed closure of the operative field compared to the stabilization with the AO plate.

3.8. The femoral shaft

The femoral shaft is made of a compact substance. War wounds of the shaft are usually accompanied by comminuted fracture. [3,8,9] In case the comminution is up to 3 cm the stabilization and neutralization of the femur is performed with a unilateral frame and six convergent pins .(Fig.28.) If the comminuted fracture is larger than 3cm, the stabilization can be performed with either a Delta or a " V " frame, with 8 to pins, depending on the size of the fractures and the fragments.

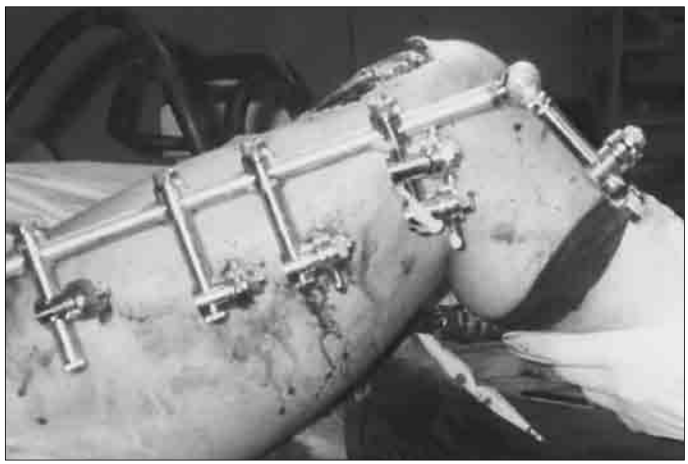


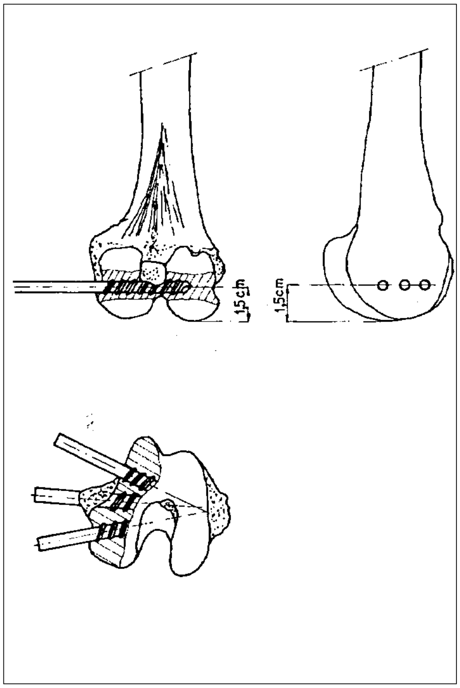
Fig. 28.

3.9. The knee

The femoral part of the knee joint is made of convex bodies of the lateral and medial condyles. The lateral condyle is curved in the anterior-posterior aspect which provides only flexion and extension. The medial condyle is curved in the anterior–posterior direction and around intercondylar fossa, which enables rotation beside extension and flexion. The condylar curves in the anterior-posterior directions are the most important for the mechanism of the joint. Regarding the condylarcurve the anterior part has the largest diameter, the intermediate part a smaller diameter and the posterior the smallest one. In this way, the collateral ligaments are loosened in flexion and fully tightened in extension. The tibial part of the joint: the condyles which are both incongruous with the femoral condyles, the medial surface is wider and partly concave. The incongruity of the femur and tibia is adjusted with the medial and the lateral meniscus, while the stability of the joint is provided by the active and passive stabilzers of the knee.

The important stabilizers are the anterior and posterior crucial ligaments, two massive and strong ligaments, stretched between the tibia and femur. They are crossed twice, firstly around their axes and secondly around each other. In each position of the knee, there is always at least one part of the ligaments tightened. The patella, placed in front of the femoro-tibial joint, is incorporated in the tendon of the femoral quadriceps muscle. The distance of the capsular attachment point to the femur in relation to the joint cartilage is more remote in the anterior aspect than in the lateral and posterior, while the attachment point to the tibia is closer to the cartilage. The epicondyles lie out of the joint capsule.(5,7,12)

When immobilzed, the joint capsule becomes hyperaemic, according to Finsterbuch, in 15 days, and in 6 weeks' time becomes fibrous and proliferates creating visible placs, panus. An injured cartilage produces adhesions to the synovia; aerobic metabolism and working capacity decrease, according to Romash, ligaments weaken and muscles become atrophied.



Sch. 8.

Proliferation and adhesions of the joint and the irreversible changes to the cartilage as well as the loss of muscles can be prevented by joint movement and early mobilization. This will also stimulate rearranging of the ligament fibres. War wounds in the knee region, intra-articular and extra-articular, are associated with heavy bleeding, frequent lesions of the popliteal artery and often disability of the young people. (5,7,12)

In order to lessen or avoid disability it is necessary to perform an adequate debridement and the correct anatomical position of the bone fragments, enable an early mobilization of the joint by the proper stabilization of the fragments to prevent infection. In the beginning of the war, the extra-capsular and intra-articular fractures of the distal femur were most often stabilized with an external fixator performing transitory arthrodesis. (4,6,9)

After such a stabilization it is difficult to obtain a good function of the knee within the first three months. (8,9) A great number of the injured would finish their treatment with the knee contracture of the various degrees, depending on the reduction, the length of immobilization, the extent of the bone defects, motivation, possibility of adequate physical therapy and skin and muscular defects.

In order to achieve an early mobilization of the joint, with an adequate stabilization by the Mitkovitsh fixator, the articulated tension device needs to be applied. Stabilization of the distal femur fragments in extra-capsular injuries (Sch.8) is performed with three pins inserted into the transversal plane.

The lateral epicondyle, which serves as a guide for the pin insertion, is palpated, and, if needed, Kirschner wire is inserted in the joint. Three pins are inserted, fixed to the mobile connection which is then fixed to the frame of the fixator and three convergent, proximally inserted pins. (8,9)

Y and T – shaped, intra-capsular fractures, should be anatomically reduced and the means of the reduction forceps until the pins are inserted. The stabilization is achieved if the axis of the tension device is placed in the knee axis, on which a mobile connection is mounted with two pins on it, which are then to be applied into tibia. The fixator applied in this manner provides the necessary stability of the bone fragments, and at the same time a gradual and even burdening of the articular surfaces, maintaining the same size of the articular space. An early mobilization is achieved within 7-10 days, and during the hospitalization the patient and the family members are trained how to use connection. The connection has a thread of 100 and the improvement in the knee function can be observed daily. When the bone consolidation is achieved, perform complete deblocking of the tension device. This should not be taken off for about ten days but enables active movements of flexion -extension with unchanged bone stability and maintenance of the same joint distension. After radiologically proved bone consolidation, the articulated tension device and pins from the tibia may be removed, while the other parts of the fixator remain on the femur until the complete bone consolidation. (5,7,12)

In injuries of the whole limb (femur and tibia), the solution for stabilization of the bone fragments is with two fixators and the articulated tension device (Fig.29.).

Even with measures undertaken for an early mobilization of the joint, there will be contractures of the knee. Before deciding about redressing, it is necessary to do the arthroscopy and arthrolysis in local anaesthesia. For the local anaesthesia we need 40ml 2% xylocsine+drenaline; 20 ml of xylocaine should be administered pericapsularly at the joint level from the lateral to the medial direction, and the rest of the xylocaine, from lateral to medial direction, parapatellarly. Approximately 10 ml can be administered into the joint. Do not give anaesthetic into the popliteal fossa! During the arthroscopy saline for irrigation drainage should be in a cuff under the pressure of 150-200 mm Hg. Thus, the joint is distended to the maximum, and such a pressure has the role of decreasing the knee joint perfusion. Care should be taken not to cause the compartment syndrome! (8,9)

Plain, smooth and fresh intraarticulares fractures of the tibia can be treated with a fixator or a screw, while the reduction is done under the control of the arthroscopy.(3)

When the arthroscope is in the joint, irrigate the knee, remove haematoma, and then you can see the diastasis of the fracture. Insert a thick Kirschner wire percutaneously through the fragment, using ligamentotaxis and osteotaxis, Kirschner nails, do the reduction and temporarily stabilize the fragment with Kuncher nail. With another Kirschner nail stabilize the fracture and if needed, correct the reduction. Then ,perform the percutaneous stabilization with cancellous bone screw or pins from Mitkovitsh fixator (war wounds). (3) The next step is the arthroscopic control of the reduction and complete arthroscopic diagnostics of the whole knee. A drain should be placed in the joint. If it is not possible to perform reduction and fixation in such a way, usually in old fractures, there is always the possibility for blood reposition. (4,6,9)

Fig. 29.

3.10. The lower leg

The lower leg extents from the tibial tuberosity to the basis of both malleoli, bone skeleton is made of the tibia and fibula with interoseal membrane in between. The tibia is a long bone in a direct contact with the femur, through which weight bearing is transmitted. (3) The tibial shaft changes its shape at the junction of the middle and distal thirds of the lower leg and it is the most vulnerable part to injury in peace-time trauma. This part of the tibia and the respective skin layer are poorly vascularized which results in slow healing, nonunions and skin problems. (3)

According to the pathoanatomical changes, war wounds of the lower leg can be:

a) soft tissue injuries, with damage of the muscle and skin alowe,

b) bone tissue injuries, comminuted, with damage of the bone tissue, spiral, segmental, associated with soft tissue injuries

The external fixation with Mitkovitsh fixator usually stabilizes the lower leg with 4-6 convergent pins and, if needed (segmental fracture), more pins can be used . (5,7,12)

In order to maintain the fibular length and preserve the ankle mortise, a semi-circular frame can be assembled and the fibula stabilized. (4,6,9) (Fig.30.)

In close fractures of the lower leg, two pins are inserted percuraneously, distally and proximally from the fracture. After a small incision, remove the haematoma and interpositum, perform the reposition and stabilization of the lower leg with an external fixation placing pins alternatively, distally and proximally. (3)

Although we have an X-ray machine with monitor in our operating theatre, it is not used for treatment of the lower leg, because percutaneous stabilization did not prove to be better than the described method in the treatment of the lower leg.

3.11. The ankle

There are many joints of the foot, but concerning biomechanics and motions, the upper and lower ankle joints are of utmost importance.

The upper ankle joint is the joint between lower leg and talus. The convex part of the joint is the body of the trochlea of talus with its articular surfaces. The trochlea of talus is convex in the anterior-posterior direction and concave in the medial-lateral direction, broad in front and narrow posteriorly. While standing up the trochlea can be incarcerated between concave part of the ankle. The concave part of the ankle is formed from the following surfaces: articular surface of the tibial maleollus, articular surface of the fibular maleollus and articular surface of the tibia.

The lower ankle joint consists of two joints:

a) anterior (talo-calcanonavicular),

b) posterior (subtalar).

Stability to this joint is given from ligaments and muscles that provide fine motions in the joint.

The Weber's classification is the most usual in surgical practice, based on the position and level of the fibular malleolus fracture in relation to the tibo-fibular syndesmosis. The Lauge-Hausten's classification includes the complete pathogenesis of the ankle injuries. (4,6,9)

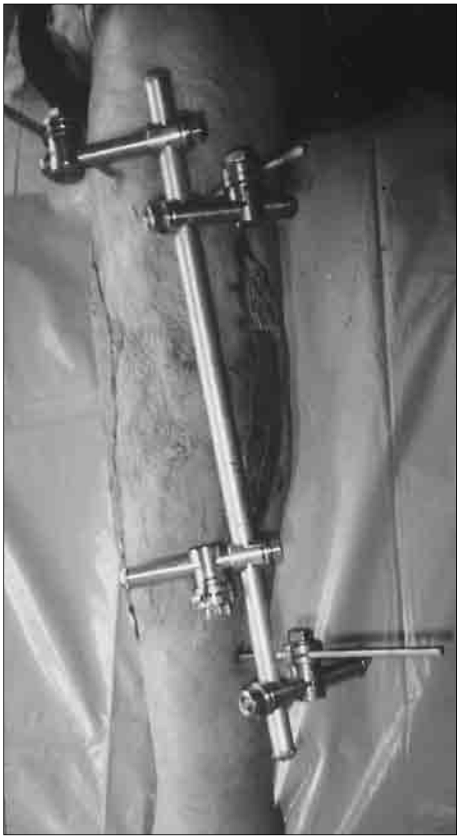


Fig. 30.

In war wounds, injuries of the ankle are severe and associated with a significant invalidity. One of the conditions for obtaining a good function is an anatomical reduction and an adequate stabilization. Stabilization of the intra-articular injuries in war wounds, with osteotaxis and ligamentotaxis method (two pins into tibia and one into calcaneus and the first metatarsal bone), transitory arthrodesis requires long term immobility of the ankle. (3) Placement of articulated tension device, its axis into the axis of the injured joint, obtains mobility.

In injuries of the posterior tibial third (Volkmann,s triangle), assemble semi-circle by the means of mobile connection and articulated tension device, thus a pin or wires with olive could be placed in the fragment in posterior-medial direction (Fig 31.).

Bimalleolar fractures of the ankle are associated with upper ankle injuries and there are no isolated injuries like in peace-time trauma. [3] The treatment of the upper ankle and lower leg will also solve the problem of the malleoli. (Fig. 32 a,b) The location for the pin application is determined by the war wound itself. [7,9,14] Assembling this fixator by the means of mobile connection and articulated tension device and creation of the semi-circles provides stability of the malleoli.[4,6,9]

Fig. 31.

3.12. The Foot

The basic function of the foot is weight-bearing of whole the body. When standing up the foot receives the weight and transmits it to the surface, while walking, the foot lifts body from the surface. The foot has two longitudinal and two transversal arches. The longitudinal medial arch is made of the calcaneus, talus, navicular, cuneiform bones and the first metatarsal bone. The lateral arch consists of the calcaneus, cuboid and the fifth metatarsal bone. The anterior transversal arch extends from the first to the fifth capitulum of the metatarsal bones, while the anterior consists of the three cuneiform bones and the cuboid bone.[12] Stability to the foot while standing up is provided by three points: the posterior calcaneus tuberosity, and from the anterior side, the capitulum of the first and fifth metatarsal bones. The

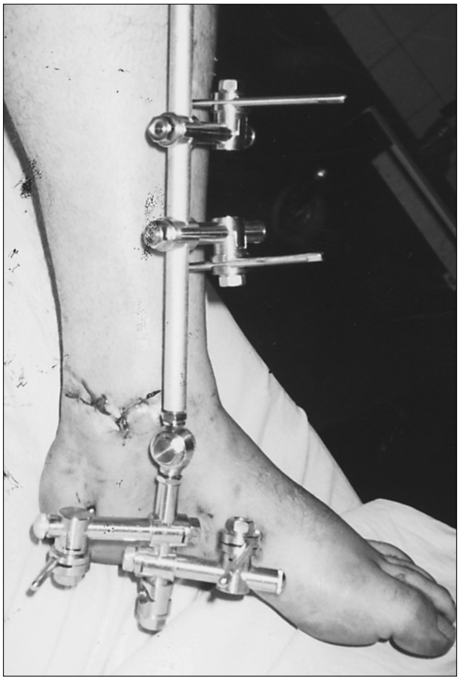


Fig. 32a.

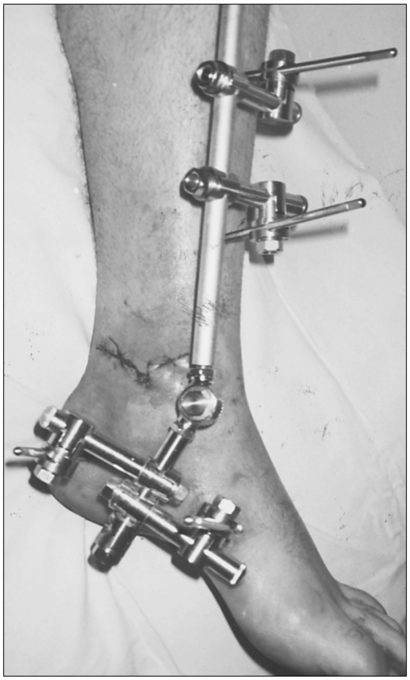


Fig. 32b.

Fig. 33.

relation in burdening between the calcaneus, first and fifth metatarsal bone is 3:2:1. War wounds of the foot, if the foot is not amputated, are severe, with comminuted fractures, bone and soft tissue damage. Usually, the whole foot is injured, associated with lower leg injuries. The in and out gun shots of the foot are rare. (5,7,12)

In calcaneus injuries associated with the lower leg injuries insert a pin through the intact skin in the calcaneus and perform the reposition and stabilization of the fragments.(Fig. 33.) Place the articulated tension device at the ankle level and its axis which is going to obtain an early mobilization. If there is a need to reinforce the stability, insert a pin in the first metatarsal bone (care must be taken not to injure dorsalis pedis artery!). Place the necessary number of pins (four) on the frame, and in comminuted, segmental fractures, if associated, insert more pins(6-8). (12)

In foot and metatarsal bone injuries, use Mitkovitsh fixator of the following dimensions: frame –100mm, mobile connections –30mm, pin 50mm. The fixator will provide stability and neutrality of the metatarsal bones and will enable futher procedures.

Such a stabilization of the metacarpal bone fragments has many advantages in treatment compared to the plastering and Kirschner wires.

3.13. The spine

In the last twenty years great changes have happened as a result of the conservative treatment; and on the other hand, technological improvement in diagnostics and development of the osteosyntetic material for the spine stabilization.

The conservative treatment has its role in treating the injured spine. Most authors think that a surgery should be performed within six hours from the injury, when:

a) 1-there are neurological disorders after the spine injury,

b) 2-progress of the neurological disorders after the spine injury,

c) 3-instability of the injured spine.

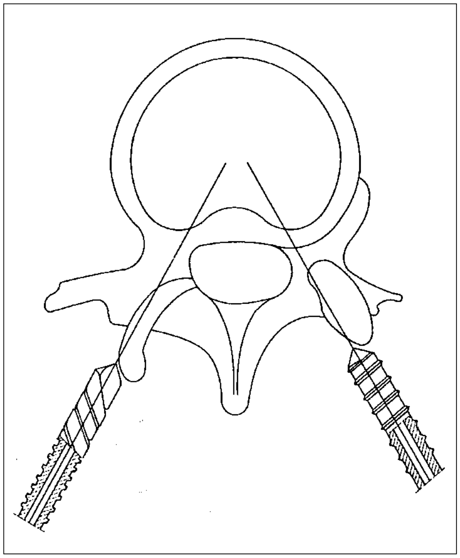
Most authors (Roy Camille, Saillant, Böchler, Rathke, Schlegel) recommend the posterior approach. There are many methods for stabilization of the respective segment of the cervical spine, ant it mainly means the fixation of the occipital bone and certain vetebras (usually third cervical vertebra).Wires, screw and Magerl plates are mainly used as osteosynthetic material.(12)

Today, stabilization of the lower cervical spine is mainly performed from the anterior sude. It can be achieved with cortico-cancellous bone graft placed between the two bodies of vertebra, on the injured vertebra body or in the location of the disc lesion (Cloward, Robinsin).Walter plate or X-shaped plates are used. The thoracic and lumbar spine should be mainly treated by the transpedicular fixation using the posterior approach. Transpedicular stabilization of the spine began in 1963. with Roy Cammille, who, besides two plates placed from posterior side, stabilized the spine by inserting screws through the pedicle, in the vertebral body. In 1977. Magerl performed the fixation of the injured spine with his frame by which he obtained a great stability and which allowed further corrections. Daniaux published his experiences in transpedicular cancellous bone grafting of the injured vertebra, while Wördsdörfer did the same on the possibilities of indirectly reconstructing the broken vertebra by the means of distraction. Fixation with osteosynthetic material, which passes through the pedicular mass and vertebral body, stabilizes the injured vertebral body. (7,9,14) Roy Camille used Walter plates for the fixation. The internal fixator with Dick, Kruger, Olerud-Ninkovic are used in the last few years. (12) The method of performing stabilization of the injured spine with external fixator is to insert a Schanz screw into the pedicular mass and make the reduction. Fixation is made with a frame placed into the compartment near spinal processes. It is not possible to stabilize the cervical spine due to the poor pedicular mass. (5,7,12)

Magerl was the first to construct a fixator for external fixation of the spine. An insufficient number of studies on external fixation and stabilization of the spine still leaves this field unexplored. The spine injuries are treated in properly equipped hospital with a fewer number of the highly specialized surgeons due to the severity and seriousness of the injury.

War wounds is the spinal region (thoracic and lumbar) are associated with extensive skin and muscle damage, fractures of the arch, transversal process and vertebral body, as well as with neurological deficiency. For the stabilization of such injuries Mitkovitsh fixator is needed and, if possible, a mobile X-ray machine.(2,12,17)

The fixation is possible because average width and height of the lumbar pedicular mass is 32,57mm and 22,47mm, and of the thoracic pedicular mass is 29,27mm and 20,23 mm.Using the posterior approach, release the small joints preparing the subperiosteum. (7,9,14) This will give a clear view of the joints which have to be precisely identified. In the thoracic spine the pedicle is drilled 3mm lateraly from the middle of the lower third of the joint border, while the lumbar vertebra is drilled in the line going beside the lateral border of the articular process, where this line cuts the middle of the transversal process of the vertebral body. A Kirschner wire has to be moved for 100-150 and under the control of the X-ray inserted into the pedicle of the vertebral body (Sch. 9.). Use the 3,5mm drill bit to thread the cortex. The drill bit is hollow and uses inserted Kirschner wire as a guide. It is enough to drill the cortex and the pin alone will thread the cancellous bone of the pedicle and vertebra (Fig. 34).



Sch. 9.

My "experience" in this field consists of Mitkovitsh fixators applied on five cadavers.

4.0. ILIZAROV EXTERNAL FIXATOR

In 1950, Gavrilo Avramovic Ilizarov from Kurgan designed the most famous fixator using Kirschner wires instead of pins, usually 1,5-2 mm thick. This fixator has become known worldwide and has been used a lot because of its multiple purposes. The fixator is made of perforated circles which can be dismantled into semicircles, four telescopic frames with nuts to connect the circles. (Fig.35.) Depending on the treatment it is possible to construct enormous variations with this fixator. The Kirschner wires are applied into the bone fragments in one plane and at 90 degrees angle, percutaneously, cross positioned. While applying Kirschner wires avoid tightening of the skin and muscles.

After placing the wires under tension they are fixed for the ring. When an adequate number of rings have been placed they are connected by a telescopic frame. In traumas it is necessary to remote the rings from the broken fragments.(2,12,17) When the fragments are more mobile and their contacts less, which requires neutralization of the muscular activities, 3-4 rings have to be applied. It is the method of curved wires or Kirschner wires with olive. Kirschner wires placed

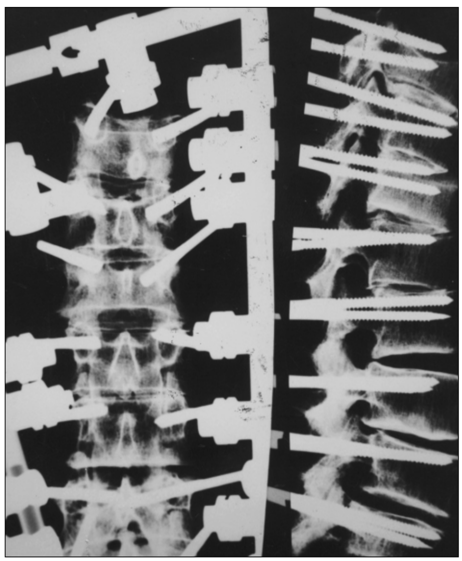


Fig. 34.

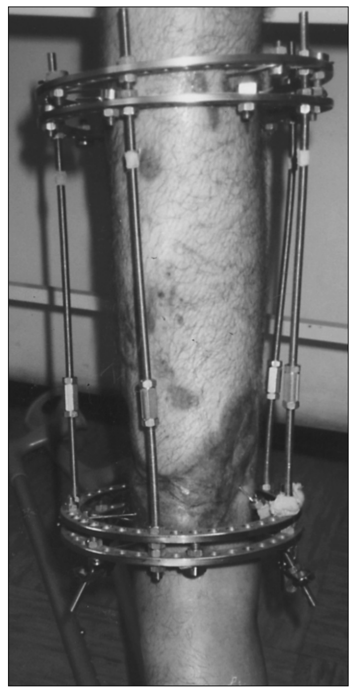


Fig. 35.

under tension together with telescopic frames enable an equal compression from all parts of the ring, and elastic fixation provides an optimal biocompression. Ilizarov introduced the term of corticotomy, meaning cutting of the cortex and at the same time preserving the periostal and medullar perfusion. It is performed with a special chisel. In orthopaedic surgery, when there are deformities of the bone, corticotomy is performed after the preoperative planing and adequate placement of the rings. For the treatment and stabilization of the bone fragments in war wounds, this fixator is of no use in primary treatment of the wound because of the following reasons:

a) long lasting application,

b) telescopic frames do not allow an easy approach to the wound,

c) reconstructive procedures on the soft tissues are more difficult,

d) it is expensive.

It has great possibilities for the treatment of bone defects and complications of war wound:

a) restitution of the bone defects without usual grafting. With such an application of the Ilizarov fixator, compression in the place of the defect, elongation and compensation of the bone graft in the place of corticotomy are provided.

b) Application of fixator for treatment of existing purulent infection.

c) Percutaneous, bloodless treatment of the pseudoarthrosis.

d) Treatment of the closed fractures of the metaphysis and diaphysis.

e) Correcting deformities of the long bones, joints and joint contractures according to the original Ilizarov applications.

f) Elongation of the extremities with distraction of the cartilaginous epiphysis.

g) Traction of the bone defects, with traction in the longitudinal and transversal directions.

h) Treatment of the unequal length.

i) Arthrodesis of the main joints.

S.V. Gljuljinazareva was following up the radiographic changes in the bones being distended by the methods of distraction-compression and concluded the following:

a) In initial radiographs, in regeneration phases osteoporosis is noticeable,

b) In the later phase radiographs show more homogeneous, more compact structure,

c) Occurrence of a resorbtion zone, during regeneration, in the phase of fixation, is a bad prognostic sign.

5.0. HOFFMAN'S EXTERNAL FIXATOR

In 1938 a Swiss Raoul Hoffman designed a fixator, which became used worldwide as well as here, in treatment of war and peace-time locomotor system trauma and also in orthopedic surgery.[12] The original version has undergone changes, but the basic construction and idea has remained the same. Changes were done by Ray, Vidal and Adry which improved static and dynamic features and ways of application of this fixator.(Fig.36)

It is produced in three sizes and it is convenient for application on any locomotor system parts, as well as in children trauma.[12,15,18]

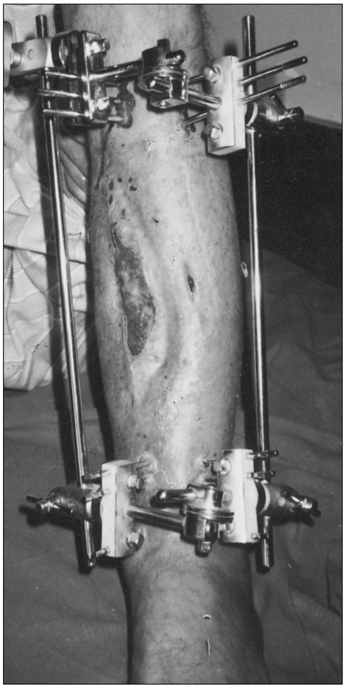


Fig. 36.

The fixator consists of clamps coated with insulating material on the inside, which prevents closing of the electric circuit between bone fragments.

After initial skin incision, self-threading pin are applied with a special drill guide. [12]

Pins are placed in one plane, in groups of four pins to the one clamp. Distal and proximal clamps are connected with a gliding rod, which enables compression and distraction of the bone fragments. This type of fixator can be used as an unilateral, bilateral, triangular and quadriangular. [2,12,17] If the treatment of the war wounds of the proximal humerus is done with the Hoffman external fixator, pin should be placed in the scapular spine. (12,15,18)

It is enough to stabilize the humerus with the unilateral al frame, as well as the radius and ulna. In the femur, it is necessary to construct delta, triangular or quadrilateral frame for the stabilization of the bone fragments.

For pelvic stabilization with Hoffman`s fixator, the Slatisž construction of trapezoid frame is required.

Mounting of bilateral constructions is convenient for arthrodesis of the ankle. With application of a bilateral frame, the compression is in the place of defect. (12)

6.0. VOLKOV-OGANESIAN EXTERNAL FIXATOR

The treatment of direct and indirect war wounds of the joints often leads to various difficulties, which cannot be solved easily. The patients are young men, with a life time ahead, and joint contractures can limit their working capability.

This type of fixator is the first choice in treatment of the bone and fibrotic ancylosis, neglected strains, periarticular nonunions, pseudoation of the fragments in war wound and corrective osteotomies in treatment of congenital limb deformities. This high technology fixator is primarily meant for ancylosis of the elbow, knee and foot and therefore, due to its high price, should be used accordingly.(12)

The Oganesian external fixator (Fig. 37.) is composed of two to three clamps of different construction, connected medially with three to four semicircles, through which Kirschner wires are placed. (2,12,17) The angle between the wires and bones is 90 degrees. Two clamps have a great mobility in anterior-posterior and lateral-medial directions and flexion and extension are possible in each joint. These clamps also enable compression and distraction. (12,15,18)

Fig. 37.

During application of the fixator its axis and the axis of the joint should be in the same plane. In this way, a gradual and proper bending of the fixator and an equal burdening of the joint surfaces is possible, while the pressure on the soft tissues and joints is avoided. With this procedure, joint contractures are treated continuously and slowly, without changing the intra-articular space between the two ends of the joint. A good mobility of the distracted and hinged joint enables realization of the axis. (2,12,17) Application of the fixator to the joint requires distraction to l or 2mm. X-rays, taken before and after application, show whether distraction was satisfactory. After application and direction of the knee joint, arthroscopic arthrolysis and removal of foreign bodies and ruptured menisci should be performed if needed.(9,12,18)

Application of the fixator eliminates the joint contractures and regains full flexion, extension, restoring function of the joint. The contracture will be eliminated using the clamps for flexion and extension and moving it for 1 mm every day (middle clamps), which is equal to 3 degrees of flexion or extension, until full flexion and extension are achieved. In the second procedure on the third frame can be up to 3-4 mm, corresponding to 90-120. The period of treatment is between 7-8 weeks, depending on the contracture itself, the patient`s age and the damage to the joint. The fixator will be kept in place until the full and (within few minutes) painless flexion and extension are possible. During the treatment with this fixator, an adequate physical therapy, supervised by a specialist, should be introduced. When full function is established, (which is achieved in few minutes) active exercises, sparing the joint, should be undertaken for 8 to 10 days. (2,12,17) After that, fixator should be removed and active physical therapy continued. Histological studies (according to Oganesian) of the newly formed surfaces in the joint ends, have proved its restoration. Fibro-cartilagenous and hyaline joint cartilage are correctly formed in 3 to 4 months. (7,9,14)

6.1. Ortofix

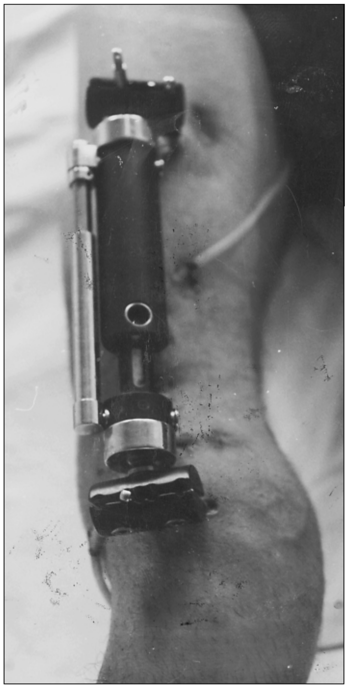


Fig. 38.

The Ortofix, a unilateral external fixator, from Verona, was designed by De Bastiani in 1984. It represents a modern technological solution. (12,15,18) It is made of two clamps, connected over two ball-shaped joints with a central telescopic frame. It is possible to place four pins in each clamp in one plane and at the same distance. The mobility of the clamps is obtained by ball-shaped joints. It is mobile in all planes, adaptable to anatomical segments, with safe blockade of the connection in the needed position. (Fig.38.)

Pins are strong, conically threaded, which makes their application easy. This provides more stability in pin-bone contract, facilitates the removal and decreases occurrence of infection around the pin. (9,12,18) Termonecrosis of the bone is minimal, and after the first rotation of the conical pin pain disappears. The central part of the fixator is the telescopic frame with the mechanism for compression, distraction and biocompression. Biocompression is transmission of the muscle tension and body weight directly through the bone, while movements of torsion, transmission and bending are prevented. This fixator is produced in high technology and weights 580-650g.It is reusable but very expensive. In war wound, with large defects of the skin and muscles, segmental fractures and significant comminution and bone defects, this unilateral fixator hardly maintains the stability of the bone fragments and neutralization of the injured bone. Thick pins may be applied only in the long bones such as humerus, femur, tibia and maybe radius and ulna. This type of fixator is too expensive for a country at war. It can be used for the stabilization of bone fragments in in and out gunshot wounds with smaller defects of the skin and muscles, and not more than a 2 cm long bone defect. The Ortpfix fixator is the choice for external fixation in the following complications:

a) pseudoarthrosis with infection,
b) prolonged healing,
c) diastasis of the symphysis,
d) and as a new type for the treatment of the inequality.

The unilateral Ortofix frame achieves stability by the mechanism of distraction and compression of the telescopic frame, which is used in bone healing as well as in orthopedic treatment of the bone inequality.

7.0. CHARNLEY FIXATOR

In 1948 British orthopedic surgeon John Charnley invented a simple and a cheap fixator.(Fig.39.) It consists of two to four pins and pinholders which have butterfly nut for the pin fixation. The pin holders connect threaded, external rods, between needed number of nuts. During the construction of the frame pins are placed in one plane at adefragments (humerus, radius, ulna), while bilateral delta frames should be used for the leg (femur, tibia). Threaded rods and nut allow compression (up to 500N) and distraction between bone fragments. Due to the limited mobility of the pin holders it is necessary to define distal and proximal points for two pins and insert

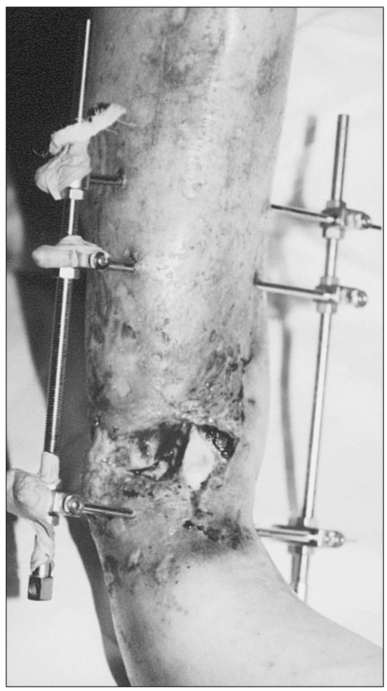


Fig. 39.

them. After that, one should apply frame and needed number of pins. Transfixation pins are used in construction of the bilateral frame. [9,12,18]

Application of the delta or triangular frame is slow, because it requires precision for the pin insertion and limited mobility of the pin holder to the frame. Since a single rod tends to bend, double and threaded rods should be used instead. [12,15,18]

New models of the Charnley fixators have technical advantages: an improved pin holder mobility and easier application of the frames. A pin holder can be placed in desirable position, in convergention to 30 degrees, between two already applied nuts. he rods attached to the fixator facilitate the application of the frame. Treatment of the injured bone fragments with this fixator enables neutralization, compression and distraction of the limb. The disadvantage of this fixator in the treatment of war wounds is time consuming and slow application of the frame and pins.

8.0. AO - EXTERNAL FIXATOR (ASIF TUBULAR)

Since 1952 well-known Swiss AO group was trying to construct a universal external fixator.

The first model had a threaded rod on which nuts were placed.(Fig. 40.) Since 1970 the rod is smooth. In 1976,as a result of evolution, hollow tubes were introduced instead of the solid rod and consequently the weight of the fixator decreased. In the same year, new constructions enabled corrections of the varus, valgus and rotation. Basic components of the AO external fixator are tubes of different length, four different types of clamps for the pins and connection of the tubes, Schanz semiscrews with threaded ends and Steinmann transfixation pins, as well as accessory instruments for the application. [12,18] This fixator can be designed in three basic forms:

a) unilateral,
b) bilateral,
c) triangular.

The configuration is determined respecting the anatomical segments and severity of the injury. [9,12,18] A unilateral application is suitable for the upper limb stabilization, while bilateral and triangular frames are compulsory for the stabilization of lower limbs. The fixator provides neutralization, compression, distraction and correction of the limbs, as well as arthrodesis of the joints. [7,9,14]

The disadvantage of the fixator is the high price of the set, which can be used in treatment for two to three limbs.

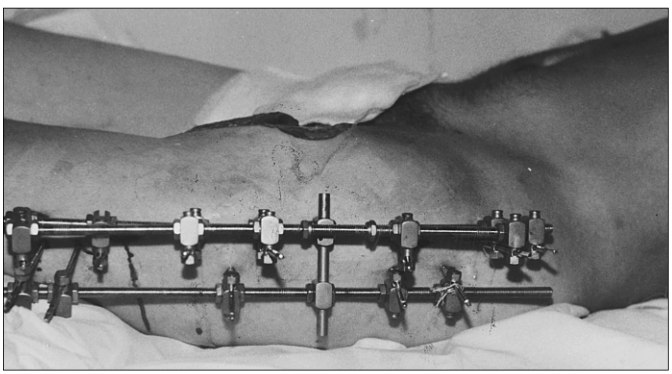


Fig. 40.

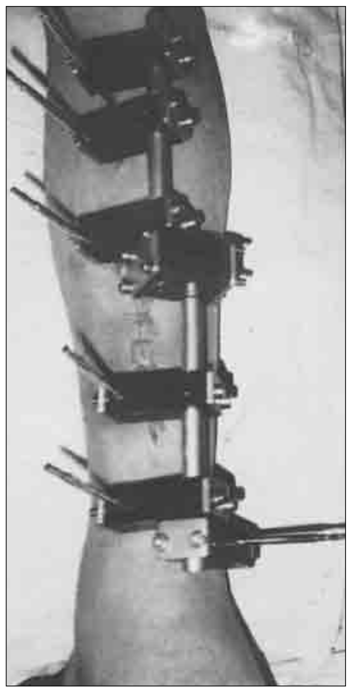


Fig. 41

9.0. SHEARER EXTERNAL FIXATOR

In 1985J.R.Shearer invented an external fixator for a single use (Fig. 41.) Specially sterilized with gamma rays, 25 kGray, and packed in sets in two sizes:

a) set for lower and upper leg and,

b) set for forearm and upper arm.

Set includes a unilateral frame with two tubes connected in the middle with a special articulated device. The connection enables application of the tube from unilateral frame in desirable length in the limb and at the same time, if needed, compression or distraction. (9,12,18) The articulated device enables the frame to follow the anatomical axis of the bone. Six highly mobile connections enable application of the convergent pins at 600 angle towards the bone axis. The place for the junction of pin and mobile connection is fixed, requiring precision in application. The most proximal and the most distal pins should be placed first and then frame fixed.The rest of the pins should be placed subsequently, proximally and distally.(9)

After the reduction, the needed compression between fragments could be obtained by the device for compression.

This type of fixator is used in many European armies and in peace-time traumas. (12,15,18)

After using both, this and Mitkovitsh fixator, I prefer Mitkovitsh fixator because of the following reasons:

a) faster and more simple application,

b) unlimited number of various applications in war time, depending on the therapeutic needs,

c) cheap, concerning the possibillity of multiple use,

d) easy to manufactore in war time.

10. "VMA BELGRADE" EXTERNAL FIXATOR

This fixator is unilateral (Fig.42.) made of tubular frame, four connections and four pins. The connections are mobile and mobility is increased by four half balls making a mobile connection. Places for the pin application are fixed.

11. KOTAJEV FIXATOR

Igor Kotajev from Russia constructed an external fixator (Fig.43.) and called it an osteomechanic. Wires and pins are used for the stabilization of bone frgments with this fixator. It is made of perforated semicircles, making two thirds of the circle. Such a semicircle allows application of adequate number of wires, and it is also possible, if needed, to construct a full circle. The semicircles are connected between each other with telescopic frames, which make compression and distraction possible.(9)A unilateral, perforated frame, on which pins can be inserted in one plane, is placed on the semicircle. The author recommends this fixator in both war and peace-time trauma as well as in orthopedic surgery. In the beginning of treatment wires and pins are used for the stabilization. In the course of treatment, removing of the frame changes the rigid fixation unto elastic, using biocompression and distraction achieved with telescopic ring holders. It is unsuitable during the designing of the frame because of different sizes of the nuts which slows the application. (9)

In war and peace-time trauma, depending on the injury, it has advantages because both rigid and elastic fixation are available. (7,9,14) The access to the wound is good since it always requires two semicircles and several unilateral frames. (12,15,18)

13. AESCULAP-STUHLER-HEISE FIXATOR

Aesculap fixator consists of smooth and solid rods of different sizes and connections.(Fig.44.) Due to the construction of connection it is possible to fix the pin and

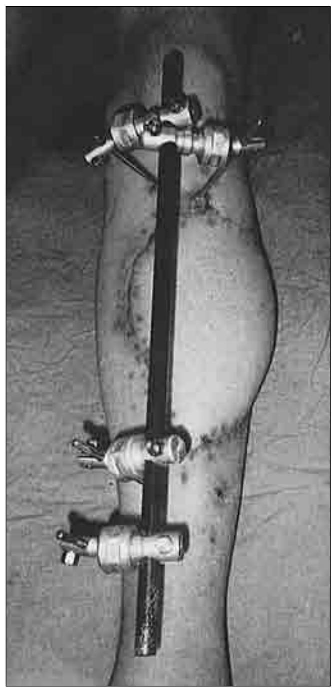


Fig. 42.

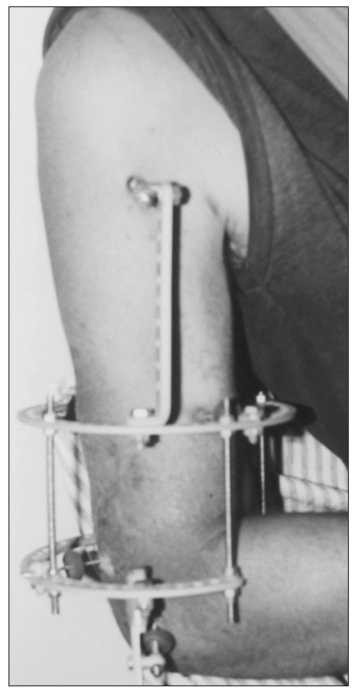


Fig. 43.

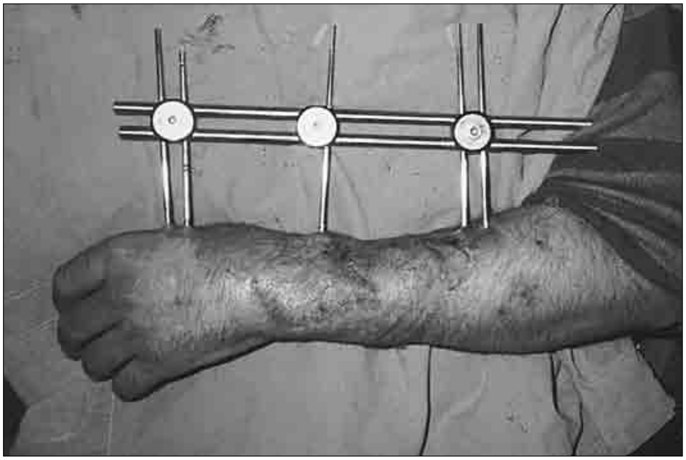


Fig. 44.

niently designed, simple for application, produced in high technology. It is produced in three sizes and three colours: mono-tube-red is the biggest one and bears the weight of 230 kg, with possibility of the 470mm bone distraction. It is used for stabilization of the femoral bone fragments (subtrochanteric, supracomdylar, T-shaped fractures). [9]

Mono-tube-blue: bears the weight of 150 kg, and 350mm bone distraction. Suitable for tibial and pelvic fractures, valgus and varus deformites. [12,15,18]

Mono-tube-yellow: bears the weight of 100 kg, achieves 250mm bone distraction and used in radial, ulnar and humeral fractures.

rod in needed position.[7] This connection enables different application of the fixator: unilateral, bilateral, triangular frame and correction of the angulation. Application of the compression device enables the compression and distraction of the bone fragments.[7,9,14]

14. FRANCH WAR FIXATOR

The fixator is a perforated tub where pins are inserted through the fixed openigs. This unilateral fixator, apart from stability in the antero-posterior aspect, has no other possibilities. [9] Beside perforations and pins, it has nuts for their fixation with the indus key. The therapeutic possibilities are very modest.(Fig. 45.)

Fig. 45.

Fig. 46.

15. MONO – TUBE EXTERNAL FIXATOR

The mono-tube external fixator (Fig.46.) is a unilateral fixator with pins. There are two clamps on the frame, each holding four pins. More clamps can be placed if needed (segmental fracture). Due to a very simple frame design dynamism of the fixator, compression and distraction are easily achieved. Fixator is very light, conve-

This type is convenient in war surgery, due to the simple and fast application, and possibilities of dynamism and compression.

The obtained stability is similar to the majority of unilateral fixators whose pins are placed in one plane and within small space.[5,12,17]

16. SABA - COOMBS

Saba-coombs external fixator (Fig. 47) is a mini fixator meant for stabilization of the metacarpal bones and bone fragments of the phalanxes. It is a unilateral type, pins are placed in one plane, there in one group and on the bearings which are placed on the frame. [9] With a special holder and nut, compression and stabilization of the pin bearings to the frame are achieved. [12,15,18]

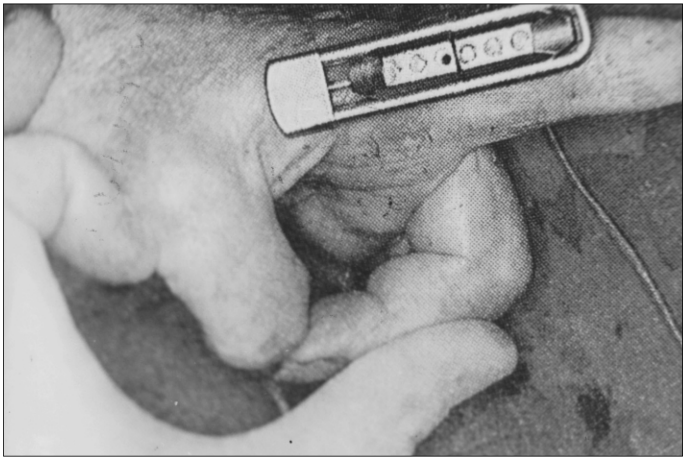


Fig. 47.

17. HEIDELBERG EXTERNAL FIXATOR

A unilateral type of fixator (Fig.48) with a universal joint and is mobile in all planes. There are connections on the frame bearing pins which are threaded during the insertion. It is easy to perform the distraction and dynamization.[1,6] This high technology appartus is reusable. It can be used in war surgery and its advantage in comparison to the unilateral fixator with one plane pin fixation is mobility of the joints in all there planes. [9]

18. MITKOVITSH FIXATOR M.9.

This fixator was designed in 1985, by Dr Milorad Mitkovitsh from Nis (Fig.49.). It consists of a perforated semicircle, a double joint and a universal clamp. This clamp enables the placement of the pins at different angles, from00 to 900. Being simple to use, this fixator enables treatment of the serial fractures and strains where union of certain segments is required.[9] It enables treatment of bone fragments of the upper arm, forearm, pelvis femur and lower leg in both war and peace-time traumas, as well as its use in orthopedic surgery.

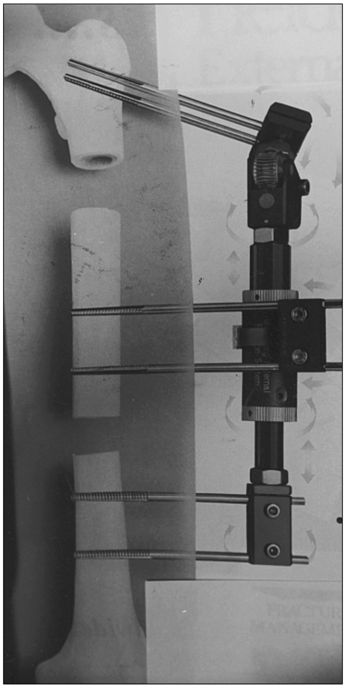


Fig. 48.

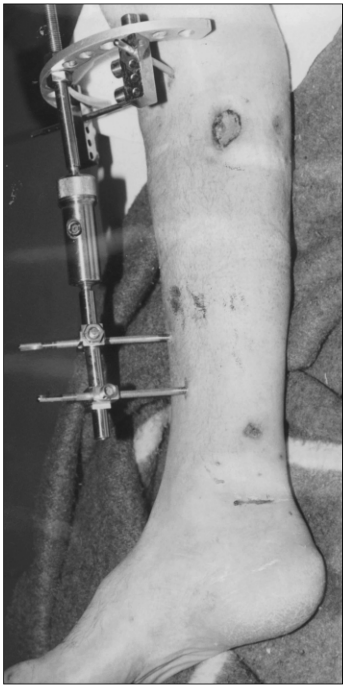


Fig. 49.

Fig. 50.

19. INSTRUMENTARIA "ZAGREB"

This fixator consists of pins (Fig.50) and threaded rods onto which nuts for the pin fixations are placed. The mobility is lessen and requires an exact pin application, which produces slow fixation. [9] The nuts are marked with S and N and it is difficult to start its application. It is possible to construct unilateral, bilateral and triangular frame. The frame is of bad quality and bends, requiring mounting of double bearings. [12,15,18]

Figure 50 shows an incorrect applying of the fixator, but in that moment there were no more fixators nor additional parts for the correct application. [12]

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