Results of Application of External Fixation with Different Types of Fixators

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SUMMARY
Introduction Extra-focal or external fixation is the method of fracture fixation through the healthy part of the bone using pins or wires.
Objective The aim was to determine which external splints (Ortofix, Mitković, Charnley and Ilizarov) had the best biomechanical properties in primary stabilization of spiral, transverse and commutative bone fractures.
Methods To determine the investigation methodology of biomechanical characteristics of the external fixator we used mathematical and computer simulator (software), juvidur physical model and clinical examination.
Results Values of advancing fragments in millimetres obtained by the study of mathematical and computer simulator (software): Charnley – 0.080 mm, Mitković M 20 – 0.785 mm, Ilizarov – 2.245 mm and Ortofix – 1.400 mm. In testing the juvidur model the following values were obtained; the external fixator Mitković M20 – 1.380 mm, Ortofix – 1.470 mm, Ilizarov – 2.410 mm, and Charnley – 2.510 mm. Clinical research of biomechanical characteristics of the effect of vertical force yielded the following results: Mitković M20 – 0.89 mm, Ortofix – 0.14 mm, Charnley – 0.80 mm and Ilizarov – 1.23 mm.
Conclusion When determining the total number of the stability test splints under the effect of vertical force (compression) and force effect in antero-posterior, later-lateral plane of cross, spiral and communitive long bone fractures, the best unified biomechanical stability was shown by the following external fixators: firstly, Mitković M20 (0.93mm), secondly, Charnley fixator (1.14 mm), thirdly, Ortofix (1.22 mm), and fourthly, Ilizarov (1.60 mm).
Keywords: external fixator; biomechanics; range of stability

INTRODUCTION

The external fixator is a device that is used in bone surgery, war and peace trauma. It is used for the fixation of bone fragments, using needles and pins that pass through the parts of the skeleton fixed for the construction of external splints. This therapeutic method with an external fixator is called outer fixation. It can stabilize and maintain the bone fragments of injury. Regarding bone fragments, the fixator can achieve: neutralization, compression, dynamization, distraction, angulations, rotation, osteotaxis, ligament taxis and elastic fixation.

Supervised surgical injuries of the locomotor system were studied in 2462 wounded patients of average age 33.73 years. An external fixator was used in the primary fracture stabilization in 1573 (72%) cases, skeletal traction in 91 (4%), and plaster immobilization of 531 (24%). In 1573 patients the following external splints were used: Mitković fixator (M20) in 1276 (81.12%), Charnley in 89 (5.9), Ortofiks in 36 (2.3%), Ilizarov in 18 (1.15%), Hofmann in 74 (4.7), AO-external fixator (Asif tubular) in 23, Volkov-Oganesijanov in 6, Mitković M9 in 5, fixator instruments “Zagreb” in 3, war “NATOV” Shearer’s disposable fixator in 18, Belgrade VMA in 7, French tubular fixator in 4, “Kotajev” fixator in 2, Aesculap-Stuhler-Heise in 11 and Mono-tube external fixator in one patient [1].

Treatment of war and open injuries of extremities are characterized by two phases. The initial phase involves primary surgical assistance, whose main goal is the prevention of early complications such as blood loss, shock, infection, ischemia of extremities and stabilization of fractured bone by external fixator [1]. This phase is short and lasts for about 7 days. We need to particularly emphasize that the adequate primary surgical treatment depends entirely on further treatment [1]. In a second or so called “reparative phase” we treated the complications, such as bone infection, pseudarthrosis, wrong growth fractures, short limbs, joint contractures, and functional outbursts.

OBJECTIVE

The aim of the study was to compare the biomechanical properties of the following external splints: 1) Ortofix, unilateral external fixator in one plane; 2) Mitković M20, unilateral fixator with the convergence-oriented pegs; 3) Charnley, bilateral fixator with pegs placed in two planes; and 4) Ilizarov, circular fixator with Kirschner’s pins and rings.

Methodology testing biomechanical characteristics of external splints was explored using: 1) mathematical and computer simulator (software solution); 2) physical model; and 3) clinical material.

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By comparative analysis of the characteristics using mathematical – computer simulators and a physical models we compared clinical material. The aim of study was to discover scientific truth, which type of external fixator had the best biomechanical solutions in the treatment of diaphyseal, transverse, spiral and commutative bone fractures.

METHODS

We studied problems regarding enriched targets to ensure the conditions and find a suitable system for testing and analyzing the biomechanical characteristics of the investigated external splints. We used the external fixator. For simulation we used mathematical and computer simulator (software) and clinical material. In the study we used four commonly used outer splints produced in our and other countries. Splints were: Ortofix, Mitković M20, Charnley, and Ilizarov circular fixator with Kirschner's pins and rings (Figure 1).

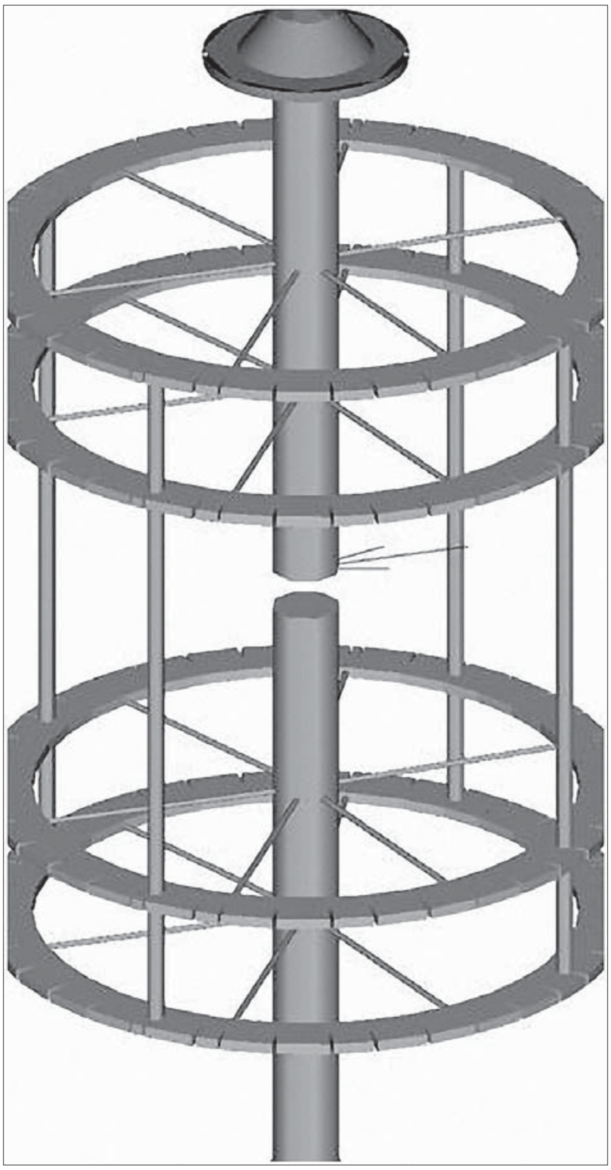

Figure 1. Mathematical and computer simulator (software) – Ilizarov fixator

The calculation model was carried out with simulations of a mathematical and computer simulator, made by foreign companies Radimpex TOWR, and PLANET PANEL PRO, which is used for plane and spatial structure calculation. The mathematical-computer model of the simulator was made under the assumption: that all nodes had rigid connection, the load was static, characteristics of materials for bone were taken from the mechanical characteristics of wood and the features of the material for the fixator was taken from the mechanical characteristics of steel. The model consisted of two equal parts, upper and lower of the same characteristics.

Using the model of simulations we estimated the effect of simulator static horizontal and vertical forces. Under real conditions dynamic force reaches its full value by 0.5 seconds, and static force in the long run reaches the final value. In practice, nodes have their own deformation, slipping and tangent line slope deformed lines is not equal to zero and the load is dynamic.

Investigation was conducted of biomechanical properties of external splints, pressure and bending exerted on the model. As the model we used a juvidur plastic pipe (PVC) prepared for each type of external splints using a unique technique. Tests were conducted to determine the effect of compression force "crack break" on the model examining posterior-anterior and later-lateral bending. The models were of the same length and using the same flat and fixed force as a tourniquet in order to obtain reliable measurements. By placing the machine in the model MIP-100-2, using a passometer, testing was done in compression, later-poster-lateral and anterior bending. Load on the MIP-100-2 controls, the scale (division 2 Newton) and dilatation was measured in millimetres (accuracy of

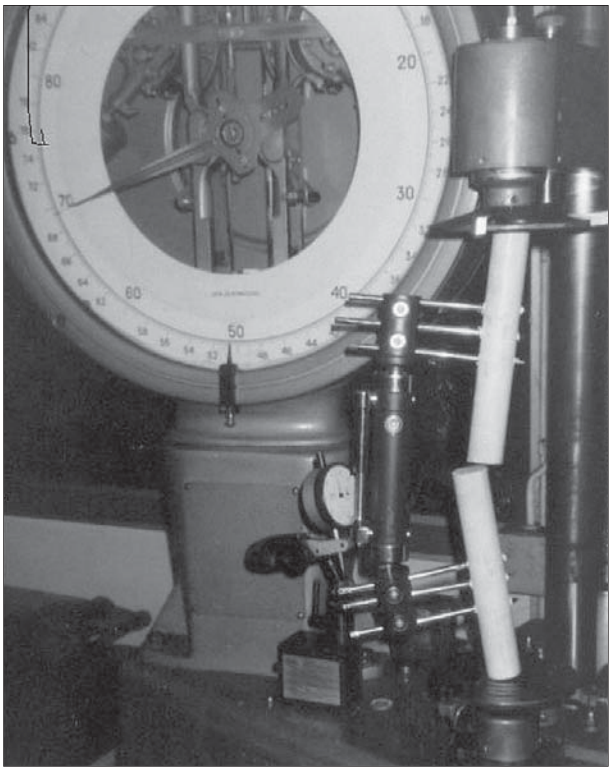

Figure 2. Physical model of juvidur – Ortofix fixsator

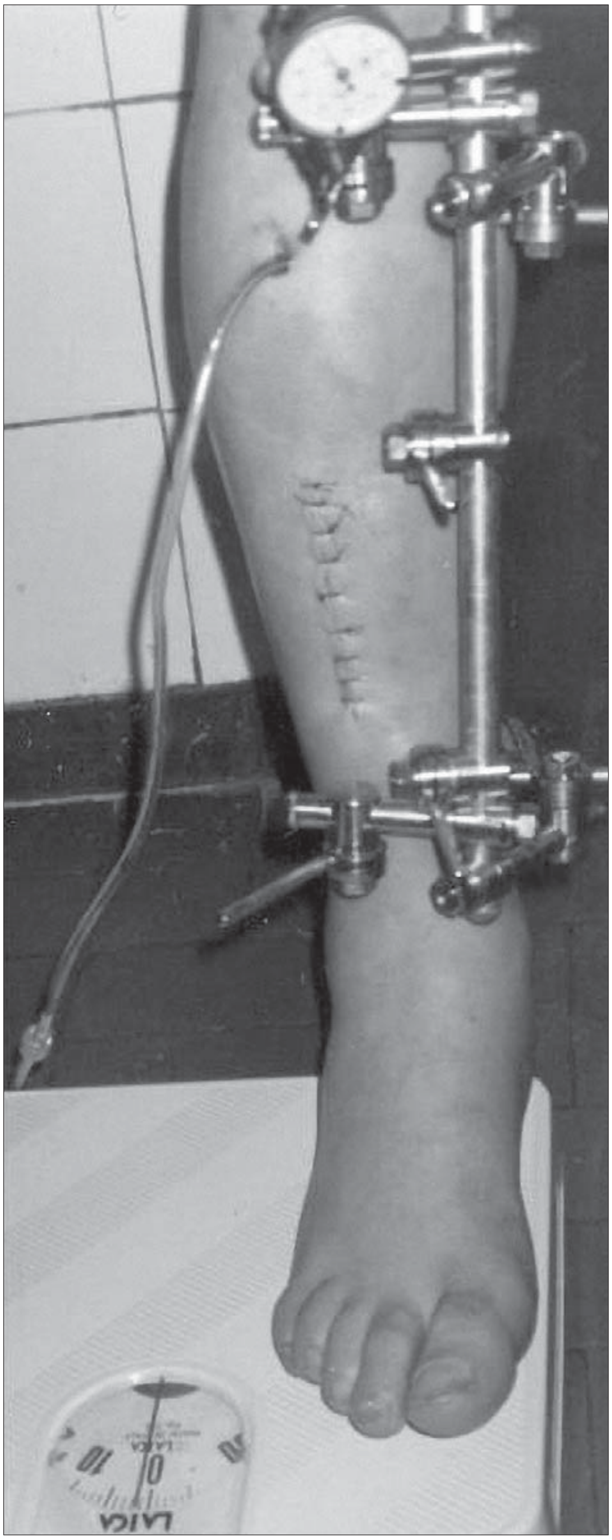

Figure 3. Clinical examination – Mitkovic M20 fixator

0.01 mm) (Figure 2). The tests were carried out in the MDP "Jelšingrad" Laboratories for Precise Measurement of Banja Luka. At this point we did not take into account the elasticity of the plastic model of the bone since the test was a comparison of results under the same conditions of testing external splints.

Clinical examination was done in 87 patients of average age 20.77 years hospitalized at Clinical Hospital Centre in Banja Luka. Stabilization of the transverse, narrow and spiral fractures of long bones, external fixator was used in the primary surgery. We used external splints Mitković in 35 (Figure 3), Ortofix in 19, Ilizarov in 21 and Charnley in 12 patients. Treated fractures were tibial in 55, femoral in 21, humerus in 9 and ulnar in two cases. The tests were conducted with comparator 14.10 700 produced by "TESA", Switzerland. Accuracy of measurements was one micron. The conductor joint that connected the comparator and external fixator was created by the firm "Cajavec" in Banja Luka. Comparator load was controlled on the scale (division/kg), while D1 dilation was measured in millimetres (0.01 mm accuracy).

RESULTS

Test results of biomechanical characteristics of unilateral external splints Ortofix with 6 pins (which were placed three distally and three proximally), with a wedge length of 4 centimetres, and with a gradual load up to 100 kg on mathematical-computer model (software solution) showed that there were advancing. For example: the effect of compression force of 100 kg advancing the pegs YP=2.8 mm, and the effect in the horizontal plane load of 100 kg was 2.56 mm.

Examining biomechanical characteristics of the unilateral external fixator with convergent set Mitković (M20) with 6 pins set (three proximal and three distal wedge set of seats "fold") and the range of 4 cm confirmed the existence of advancing wedge. The effect of force in the vertical plane of 100 kg moving wedge was yp=1.57 mm and the effect in the horizontal plane load of 100 kg was 1.56 mm.

Examining the biomechanical properties of external Charnley's splints set with 6 pins (three proximal and three distal from a distance of 4 cm) on the mathematical and computer simulator shift of the load of 100 kg in the vertical plane amounted to YP=0.16 mm, and the effect in the horizontal plane load of 100 kg was 0.28 mm.

Test results for Ilizarov external splints (with two twists the proximal and distal and 6 Kirschner's wire proximal and distal, the ring distance of 4 cm) showed force effect of the load of 100 kg. Advancing amounts of the Kirschner's wire up to yp=4.49 mm, and the effect in the horizontal plane load of 100 kg was 0.114 mm.

For testing of external splints Ortofix, the model was a standard model with six parallel wedges 6 mm in diameter, placed distally and proximally from the "fracture". Distance from the "fracture" to the nearest wedge below the fold a total number of 4 cm, some wedges between 3-4 mm, and the model of the joints splints, about 4 cm. Upon completion of testing compression force, the effect of the lateral force on posterior-anterior and later-lateral deflection was measured.

External fixator Mitković M20 was produced in "Cajavec" as a standard model, with six convergent set pins at an angle of 90° above and below the „fracture". Interval on the model above the "fold" to wedge amounted to 4 cm, between 4 cm wedges and the model juvidur joints splints to 4 cm. The upper and lower part of the model are three built-wedge, four in the same, one plane and another two in the second plane oriented to the previous converged around 45°.

For testing Charnley's external splints we used the standard model with four parallel wedges in the plane: two distal and two proximal wedge sets. The distances from the turning to crack pins amounted to 4 cm, the same as the distance from the model juvidur to joints.

Ilizarov external fixator standard model, with two rings in the proximal and distal model were placed distally and proximally up to 4 cm and 8 cm from the place of "fractures".In each ring there is a set of two Kirschner's wires (eight), four proximal and four distal. The first was used to determine the measuring effects of vertical force, then the effect of force in the posterior-anterior and later-lateral plane. For clinical trials of external splints Ortofix, we used the standard model with six pins, three wedges, distally and proximally, at the three areas of fracture. First, testing dilatation of pins was carried on the third postoperative day. Testing was done so that the external fixator set comparator in (0.00 mm) and the patient said that foot surgery relied (fit) to scale showing the time 0 kg. The patient exercised mainstay of 1 kg, 5 kg, 10 kg, and 15 kg and so on to eliminate the pain that occurred. Measuring was performed at the first, 15th and 30th postoperative day. Ambulatory controls were performed each month, when the measurement was performed, and so the bone repair. Ortofix dilatation pins in fractures on the third postoperative day was 0.00 mm, 0.1 mm in the first month, 0.2 mm on the second month, the third 0.3 mm, and 0.00 mm on the fourth month.

Processing the results obtained by clinical examination of basic biomechanical characteristics of the external fixator Ortofix, we could conclude that the greatest instability was in the third, then in the second and first month. This we explained by the fact that in this period the pins made their wedges painless slot. This disqualified the pain of soft tissue which was manifested on the third postoperative day. Still we could not establish the bone bridge between the bone fragments that would "connect" bone fragments. Using this bridge we could enhance the stability of broken bones, and bio-mechanics of external splints under full load. Fractures consolidation and ossification, i.e. the "Bone Bridge", increase the biomechanical stability of external splints with no advancing of pegs. For clinical trials of external splints Mitković we used the unilateral frame with six convergent set of pins at an angle of 90°, set along the bone with a distance of 4 cm between the pins and about 4 cm from the broken bones to the junction. Measurements and conditions were the same as at Ortofix.

Dilatation of pins on Mitković M20 on the third postoperative day was 0.00 mm, 0.2 mm on the first month, 0.3 mm on the second month, 0 mm on the third, and 0.00 mm on the fourth month. Dilatation of pins on Mitković M20 on the third postoperative day on femur was 0.00 mm, 0.1 mm on the first month, 0.2 mm on the second, 0.2 mm on the third, and 0.00 mm on the fourth month. Processing of the results obtained by clinical examination of basic biomechanical characteristics of the external fixator by Mitković we could conclude that the greatest instability was in the second, then first and third month. This explains the fact that in this period pins already made a painless "deposit", a break was not repaired prop possible full weight. The appearance of mature callus in the fourth month dilatation wedges decreased.


Figure 4. Clinical examination – Ilizarov fixator

We applied the Charnley fixator with four wedges; the wedge in two proximal and two in the distal part of the bone. Distance between the pins was approximately 4 cm and wedges were in the middle of the thread. We treated 12 patients with this fixator for fractures of the tibia. Results of the first measurements on the third postoperative day was 0.00 mm, 0.00 mm in the first month, second month 0.00 mm, the third month of 0.00 mm and 0.00 mm on the fourth. Such results are expected, because Charnley fixator stabilized maximum (prestressed) compression between the broken fragments of transverse fractures.

We used the Ilizarov fixator to treat 21 patients during the examination. The long bones included 14 tibias, 5 femurs and 2 humeri. Treatment was used with four rings of eight Kishner. Dilatation of Kirschner's Ilizarov fixator for fractures of the third postoperative day was 0.01 mm, 0.4 mm in the first month, second month 0.2 mm, third 0.2 mm, and on the fourth month of 0.00 mm.

Dilatation of Kirschner's Ilizarov fixator for the femur in the third postoperative day was 0.13 mm, 0.25 mm in the first month, second month 0.19 mm, third 0.2 mm, and the fourth month of 0.00 mm. Ilizarov external fixator for the humerus on the third postoperative day was 0.07 mm, 0.19 mm in the first month, second month 0.2 mm, third 0.0 mm, and on the fourth month of 0.00 mm (Figure 4). Processing result obtained by clinical examination of basic biomechanical characteristics of Ilizarov external fixator we could conclude that the greatest instability was present in the second, then the first and third month. As a measure for determining the rank stability splints when examining biomechanical characteristics of the mathematical and computer simulator we used the method of making the principle of minimum multicriterial determination of early stability. The point of this method is that the range is determined on the basis of gathering criteria (measures of rank), and based of values obtained by total criteria determined by the principle of maximum range or minimum; each criterion is multiplied with the so-called factor of influence. The coefficient obtained in this way summarizes the modified criterion for total criteria. Since the method requires expert assessment, the impact coefficient of vertical and horizontal plane, normalization coefficient 3 was chosen. For influence of bone defects we took the ratio of 1:1:1 1, which means that the influences of the size of bone defects were treated equally, and with equally influence. With these coefficients and the related impact, the principle of minimum rank was determined by the stability of splints obtained in the simulation of mathematical and computer simulator, PVC model and clinical examination individually.

This process results in obtaining the ranking stability splints when examining biomechanical characteristics of the mathematical and computer simulator (Table 1).

Processing the results in obtaining the ranking stability splints when examining biomechanical characteristics of the PVC model of juvidur: ranking the stability of plastic splints pipe (model) of juvidur (Table 2) and ranking stability splints when examining biomechanical characteristics of the clinical material (Table 3).

In determining the overall ranking stability splints based on the results available in the study with all three methods opened more questions: authenticity and accuracy of some of the selected methods in term of the investigated splints, mathematical and computer simulator is a very simplified and very tentatively matched to reality in which dynamics of the limbs and dynamic relationship: limb-fixator is neglected. A similar situation is the truth and validity testing of PVC model of juvidur where the biomechanical properties of the limbs replaced with full features of PVC rods. It is important to note that neither the simulator nor the plastic model contained biomechanical constraints, such as pain and the like, which further contribute to the simplification of truth of the applied models.

Table 1. Results of ranking stability splints on mathematical and computer simulator

Fixator	Vertical plane		Horizontal plane		Total	
	AR	Score	Mean value	Score	Mean value	Score
Mitković M20	0.785	2	0.280	3	0.533	2
Ortofix	1.400	3	1.280	4	1.240	4
Charnley	0.080	1	0.140	2	0.110	1
Ilizarov	2.245	4	0.057	1	1.151	3

AR – average ratio

Table 2. Results of ranking stability splints on plastic model juvidur

Fixator	Total					
	AR	SD	Results of force V (compression)	Results in AP	Results in LL	Definitive results
Mitković	2.86	2.08	1			
Mitković AP	0.74	0.59		4		
Mitković LL	0.21	0.14			2	
Mitković rang	1.38	1.77				1
Ortofix	3.79	2.78	2			
Ortofix AP	0.34	0.28		2		
Ortofix LL	0.15	0.14			1	
Ortofix rang	1.47	2.35				2
Charnley	3.97	2.85	3			
Charnley AP and LL	0.72	0.54		3	4	
Charnley rang	2.51	2.53				4
Ilizarov	4.13	2.84	4			
Ilizarov AP and LL	0.29	0.20		1	3	
Ilizarov rang	2.41	2.85				3

Table 4. Results of ranking stability of splints, average value of dilatation of pins, Kirschner's wire, comparing results of mathematical and computer simulator (a model of juvidur and clinical material)

Fixator	Mean value				
	Simulator	PVC model	Clinic	Total	Results
Mitković M20	0.53	1.38	0.89	0.93	1
Ortofix	1.34	1.47	0.84	1.22	3
Charnley	0.11	2.51	0.80	1.14	2
Ilizarov	1.15	2.41	1.23	1.60	4

Table 3. Results of ranking stability splints in clinical material

Fixator	Third day		First Month		Second Month		Third Month		Fourth Month		Fifth Month		Total	
	AR	Res.	AR	Res.	AR	Res.	AR	Res.	AR	Res.	AR	Res.	AR	Res.
Mitković M20	0.13	2	1.24	3	1.28	2	1.07	2	1.04	4	0.17	3	0.89	3
Ortofix	0.16	3	0.93	2	1.11	1	1.42	3	1.01	2	0.12	1	0.84	2
Charnley	0.01	1	0.89	1	1.44	3	0.91	1	0.95	1	0.16	2	0.80	1
Ilizarov	0.18	4	1.47	4	1.65	4	1.47	4	1.03	3	1.01	4	1.23	4

Res. – result

However, for the stability ranking and selection of splints in the given research and taking into account the degree of validity of some methods, the method chosen is the minimum mean value shifts in combination with weighting for the appropriate method that corresponds to the next algorithm:

(Rank)total = j$)_h$ = Min (a_s Av.rat.($S^i{}_{mk}$) + a_m Av.rat. (M^i PVC) + A_k Av.rat. (K^i) /3 × (an_s + an_m + $a_k)_h$ (Rank-sum) total = j$)_h$ = min (a Av.rat.$_s$ ($S^{and}{}_{mk}$) + a Av.rat.$_m$ (M^{and} PVC) and_K + Av.rat. (K^i) / 3 × (a_s + a_m + $a_k)_h$

For j = 1.2.3.4. i = 1.2.3.4. h = 1.2.3.4 where a s, and m and k coefficients of impact of certain methods of examination, i.e. simulators, juvidur models and clinics respectively. The electoral impact of coefficients and s: a m: a k = 1:1:1 (Table 4).

DISCUSSION

The complexity, specific nature and originality of every war wound require expertise, experience, attention and diligence [2]. War wounds are most frequently localised on the extremities – 70% [3, 4], of which 40% are accompanied by bone fractures [1]. Popović [4] states that joint injuries war in former Yugoslavia occurred in 5.7% of cases, of which 57.3% of cases presented with penetrating joint injuries. Gunshot joint injuries occurred in 8% of all gunshot injuries to the extremities. Piščević [5] maintains that one-third of gunshot wounds of arteries are accompanied by fractures. Reports from the war in Afghanistan showed that out of a series of 756 injured persons 20.3% sustained penetrating joint injuries with no bone lesions. Shoulder injuries occurred in 33.7%, and wrist joint injuries in 9.2% of cases [6].

The main goal of treatment of fractures is to restore full function of the injured limbs in the shortest possible time. External fixation provides biomechanical conditions that we can change. With internal fixation we can achieve rigid fixation, which can be used at the beginning of healing, but it is generally accepted that those in later stages do not provide optimal conditions. In most analyzed series the external fixator is used for treatment of open fractures. In series in which the external fixator is used in the treatment of closed fractures analyses show good results; fewer complications and faster bone consolidation [7].

Fernández [6] published biomechanical results of experimental work on models of splints. Construction of models consists of a tube of polyvinyl chloride with installation of external frame splints: unilateral, bilateral and triangular. The pins are placed in relation to the plane frame at an angle of 60°, 90° and the bone shaft under 90°. The author came to the conclusion that unilateral and bilateral configuration was far from smooth, with most unstable mounting tubes without screws. This installation provides very good stiffness without anterolateral transfiction [8].

Biomechanical analysis of Hoffmann–Vidal-frame of the external splints was reported by Shiba et al [9]. Time duration of the Hoffmann–Vidal's quadrilateral tibial configuration was tested using a synthetic bone model. After repeated cyclic tests under load there was a loosening of the joints connecting the frame bars. The conclusion reached was that such structures could be safely used for 4-5 sequential 6-monthly application if critical components were exchanged between applications [9].

Goodship and Kenwright [10] used stabilized fractures with external fixator in two groups of sheep. One group was subjected to axial fracture of advanced mechanical compression during 17 minutes (500 cycles at 0.5 Hz) every day using pneumatic cylinders connected to a carrier fixation system. Shearing was applied in 33%. Application of these movements began seven days after osteotomy. External callus appeared earlier in the stimulated groups and torsion stiffness after 8-10 days. Experimental works of Goodship and Kenwright [10] have proved that fractures in sheep after micro-movements of fixation lead to increased creation of callus. Also, experimentally produced 3 mm wide cracks of osteotomy shaft fractures in sheep, where moving in one group was 0, 5 mm and the other by 2 mm. Movements of 0.5 mm led to a degree rise fracture bone and bone mineralization in the cracks, which was considerably higher than in the control group with rigid fixation. Movements of 2 mm was detrimental to bone mineralization and in terms of growth and fracture stiffness in relation to moving from 0.5 mm [3].

De Bastiani et al. [11] showed in a series of 202 fresh fractures that open fractures required 18.4 weeks for healing of the bone, compared with only 15.4 weeks in closed fractures.

Biomechanical tests confirmed that the grouping of pins along the whole broken bone in multiple planes offer more stability than grouping pins in a small space in one plane. Reponated moving bone fragments in place of fracture of 0.5 mm ten times a day significantly increases the process of mineralization and fracture healing [12, 13]. If the shift of 2 mm and cyclically is repeated daily over 10,000 times, water inhibition of bone healing process occurs with advancing pseudarthrosis. Reponation affect bone fragments and compression at interfragmental space. Compression of 20-57 kp applied to 1 cm of bone surface allows a direct bone fragments merging, the penetration of osteoblasts and osteoclasts and the formation of lamella and osteona [12]. These conditions allow primary bone consolidation. The lowest compression is needed for the humerus, secondary to fractures of the femur [14].

CONCLUSION

Examining the biomechanical characteristics of these external splints, the mathematical and computer simulator (software), physical model of the tube juvidur and clinical material on the effect of compression force and force in the anteroposterior and later- lateral plane the most optimal biomechanical stability has external fixator Mitković M20 (0.93 mm), followed by Charnley fixator (1.14 mm), Ortofix (1.22 mm) and Ilizarov fixator (1.60 mm).

NOTE

Methodology and research results are shown here as a part of the material processed in the author's doctoral thesis [2].

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Резултати примене спољне фиксације различитим типовима фиксатора

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КРАТАК САДРЖАЈ
Увод Спољна фиксација је метода фиксације прелома кроз здрав део кости помоћу клинова или жица.
Циљ рада Циљ рада био је да се утврди који од спољних фиксатора – *Ortofix*, Митковићев, Чарнлијев (*Charnley*) или Илизаровљев – пружа најбоља биомеханичка решења у примарној стабилизацији спиралних, попречних и коминутивни прелома кости.
Методе рада За одређивање методологије испитивања биомеханичких својстава спољашњег фиксатора коришћени су математичко-компјутерски симулатор (софтвер), физички модел од јувидура и клиничко испитивање.
Резултати Вредности померања делова кости које су добијене при испитивању на математичко-компјутерском симулатору биле су: 0,08 *mm* код примене Чарнлијевог фиксатора, 0,785 *mm* код Митковићевог фиксатора M20, 2,245 *mm* код Илизаровљевог и 1,4 *mm* код примене фиксатора *Ortofix*. При испитивању на пластичном моделу од јувидура вредности су биле: 1,38 *mm* (Митковићев M20), 1,47 *mm* (*Ortofix*), 2,41 *mm* (Илизаровљев) и 2,51 *mm* (Чарнлијев). Клиничким испитивањем биомеханичких одлика при дејству сила компресије добијени су следећи резултати: 0,89 *mm* (Митковићев M20), 0,14 *mm* (*Ortofix*), 0,80 *mm* (Чарнлијев) и 1,23 *mm* (Илизаровљев).
Закључак Најбољу уједначену биомеханичку стабилност при дејству вертикалних сила (компресије) и дејству сила у антеропостериорној и латеролатералној равни код попречних, спиралних и коминутивних прелома дуге кости имао је фиксатор по Митковићу M20 (0,93 *mm*); следе Чарнлијев (1,14 *mm*), *Ортофих* (1,2 *mm*) и Илизаровљев спољашњи фиксатор (1,60 *mm*).

Кључне речи: спољашњи фиксатор; биомеханика; одређивање стабилности

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