MED ARH, 2011; 65(3): 157-159

ORIGINAL PAPER

Comparison of Stability of Different Types of External Fixation

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Stabilization of fractures by external fixator is based on the mechanical connecting of the pins, screwed into the proximal and distal bone fragment. Site of fracture is left without any foreign materials, which is essential for prevention of infections. **Aim** of this work is to compare stability of constructs bone model-external fixators of different types (Ortofix, Mitković, Charneley and Ilizarov). Stability is estimated under compression and bending (vertical and horizontal forces of 100 kg magnitudes, with distances between pins of 4 cm). **Methodology:** The mathematical-computer software (Tower, Planet and Planet Pro) was used in the laboratory for accurate measurements of MDP "Jelšingrad" company, Banjaluka. Interfragmental motions in millimeters at the appliance of vertical and horizontal forces were 2.80/2.56 at Ortofix (uniplanar fixator), 1.57/1.56 and fixator by Mitković-M20 (uniplanar fixator with convergent oriented pins), 0.16/0.28 at Charnely's external fixator (biplanar fixator), and 4.49/0.114 mm at Ilizarov's external fixator (fixator with two proximal and two distal rings, each attached on the 6 Kirschner wires). **Results and discussion:** It has confirmed that uniplanar fixation is easier and provides sufficient biomechanics circumstances in the site of fracture for bone healing, especially if the pins are oriented convergently. Ilizarov's fixator is multiplanar fixator, but its stability is dependent of tightness of wires, and provides adequate stability only in transversal plane. By other words, each fixator has its indications; selection of the fixator should be based on theirs mechanic characteristics, fracture geometry, and potential of bone healing, with permanent simplification of treatment, which has to be safe and acceptable for the patient. The main advantage of this study is its nature–the comparison of four most used external fixators, by the only one possible way–on the bone model. Each other way of comparison would result with much more questions than answers, due to unacceptable high bias of other parameters, which significantly influences on the results of the study. **Key words:** external fixator, biomechanics, stability, Ilizarov, Ortofix.

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1. INTRODUCTION

The external fixator is a device that is used in bone surgery, war and peacetime traumatology. It is used for fixation of the main bone fragments, so that the pins or nails are fixed in the main or the marginal bone fragments and are mutually connected by metal trunk. Fixator can establish a neutralizing force, compression of the fragments, their dynamization and distraction, angulation, rotation, also osteotaxis and ligamentotaxis (1, 2, 3). As a rule long bone fractures are treated with intramedullary nail or plate with screws (4, 5). The external fixator is used only in those cases where the break is widely open (grade III), war injuries, infected injuries, and in multiple injured patients. Fixation with the external fixator is generally less stable than with a bolt or plate, and requires a longer period of not walking. In addition, it is usually necessary to make the conversion of external fixation in the inner, i.e. replace the external fixator with plate or pin, after infection resolves and stabilize the general condition of the patient (1). The main disadvantages of external fixation devices are their lack of stability, prominence of implants and the need of conversion. Advantages of external fixation are minimal invasiveness during the installation, quick setup without opening of the fracture site (Figure 1).

In order to maximize the benefits of external fixation, and minimize its disadvantages, it is necessary to identify the models of external fixator to provide maximum stability (2, 3). As it is hard to pair patients in clinical studies, and complete group of patients with the same clinical and geometrical characteristics of fractures treated with different types of fixation, remains as the best solution comparison of stability of the construct fixator-model of broken bone.

The aim of this study was to compare the mechanical characteristics of the external fixators: Ortofix (unilateral fixator in one plane), Mitković

M20 (unilateral fixator with pins oriented convergently), Charnely (bilateral fixator with pins arranged in two planes) and the Ilizarov (circular fixation with Kirschner wires and rings) on the bone model.

2. METHODS

The paper analyzes the four most commonly used outer fixators at the Clinic of Orthopedics and Traumatology, Clinical Centre of Banja Luka (Ortofix, Mitković M20, Charnely, and Ilizarov's fixator).

We used a simulation of the mathematical-computer model, created by Radimpex® (Towr, Planet and Panel Pro). Mathematical and computer simulator based on the assumption that all nodes have a solid connection, that the load is static and that the properties of materials for fixation are analogue to values for steel.

Testing of the biomechanical properties of external fixators (the pressure and bending) are made on the model made of plastic pipes (PVC), outer diameter 25 mm, inner 11 mm. Tests were conducted by the effect of compression force "of the fracture crack" and the bending force in the antero-posterior and latero-lateral direction. We analyzed the four fractures 2 mm, 1 cm, 3 cm and 5 cm and calculated average value. All models had the same length, flattened, and fixed the same force in the clamp device MIP 100-2, in order to achieve the reliable measurement. The load is controlled on the scale (at least two Newton distinctions force), while a dilation was measured in hundredth parts of a millimeter (0.01mm accuracy). Tests were performed in the laboratory of precision measuring of the company MDP "Jelšingrad" Banja Luka. In this study, is not taken into account the elasticity of plastic bones model, because the study was a comparison of results under the same experimental conditions external fixators (4).

3. RESULTS

The results of tests of biomechanical characteristics of a unilateral external fixator Ortofix were analyzed in a construct with 6 pins (three pin placed distally and proximally, with a mutual distance of 4 cm and the load to 100 kg). Moving with the force of the compression pin amounted to 2.80 mm, and of the force in the horizontal plane, the shift amounted to 2.56 mm.

By testing the biomechanical characteristics of the fixator by Mitković-M20 (with a convergent set three proximal and three distal pins, with a range of 4 cm and the force of 100kg) was shown that the effect of compressive force, displacement of the pin amounted to 1.57 mm, and on the force in the horizontal plane 1.56 mm.

Charnely's external fixator (with three proximal and distal pins, the mutual distance of 4 cm and a force of 100kg) at the mathematical and computer simulator showed a shift in the vertical plane of 0.16 mm and 0.28 mm in the horizontal plane.

Test results of Ilizarov's external fixator (two rings proximal and distal, each fastened with 6 Kirschner wires with spacing between the rings of 4 cm and the power load of 100kg) showed the movement of wire 4.49 mm in the effect of vertical force and 0.114 mm as the effect of horizontal forces (Table 1).

ANOVA test showed that these differences between the fixators in shift are statistically significant.


FIGURE 1. Uniplanar external fixator on the left, Ilizarov's fixator on the right.

Type of fixator/ movement of the pins (in mm) by force	in vertical direction	in horizontal direction
Ortofix	2.80	2.56
Mitkovit M20	1.57	1.56
Charnely	0.16	0.28
Ilizarov	4.49	0.11

TABLE 1. Movement of pins as effect of compaction and shear forces (vertical and horizontal) on the mathematical and computer simulator.

4. DISCUSSION

The most important goal in treatment of fractures is to restore full function of the injured limb in the shortest possible timeframe. External fixation provides biochemical conditions which can be changed as needed. With internal fixation it is possible to achieve rigid fixation, which can be used at the beginning of healing, but it is generally accepted that in the later stages does not provide optimal conditions.

Fernandez has published results of experimental work with different models of fixation. The structure model is consisted of tubes of polyvinyl chloride with an external fixator frame mounted as unilateral, bilateral and triangular. Pins are placed in relation to the plane of the frame at an angle of 60° and 90°, and the diaphysis of the bone at an angle of 90°. He came to the conclusion that the unilateral and bilateral configuration was by far the most unstable form of assembly, when are not used screw pins. When used screw pins, it provides very good rigidity with and without anterolateral transfixion (5).

Biomechanical analysis of Hoffmann-Vidal's external fixator frame was given by Ryoichi Shiba and colleagues (6). Lifetime of Hoffmann-Vidal quadrilateral's tibial configuration has been tested using synthetic bone models. After repeated tests under cyclic loads resulted in loosening of the joints that connect the rod frame. The conclusion was that such structures can be safely used during six months, if critical components are replaced.

Goodship and Kenwright in their experiments on sheep fractures stabilized by external fixator (7). In one group of sheeps fractures was subjected to axial movement of the mechanical stimulus in the course of 17 minutes (500 cycles at 0.5Hz) every day using a pneumatic cylinder connected to the rail fixation system. Application of these movements began seven days after osteotomy. External callus has appeared earlier in stimulated group. Torsion stiffness after 8-10 weeks was significantly higher in stimulated group. Experimental works by Goodship and Kenwright have proven that the in the tibia of sheep, micro movements after external fixation, leading to increased callus formation. It was shown that the movement of 0.5 mm resulted in stronger bone consolidation and bone mineralization than the control group with rigid fixation. Displacement of 2 mm was detrimental to healing in terms of growth and mineralization of fracture stiffness, compared to the displacement of 0.5 mm.

Hante and colleagues, studied the effect of dynamic shear applied as a gradient scale from 0 to 100%, using the model of pin-shaped osteotomy. They came to the conclusion that the shear value from 0% to 20% leads to the formation of callus from healing, while the higher level of shear led to the formation of bone callus without consolidation, or pseudoarthrosis. Krettek et al showed in a series of 202 fresh fractures of the tibia, the need for open fractures 18.4 weeks until healing of bone, compared with only 15.4 weeks in closed fractures (9).

Generally, biomechanical testing, and so this, confirmed that the grouping of pins along the broken bone in multiple planes gives greater stability than the grouping of pins at a small space in one plane. Moving of bone fragments at the site of fracture by 0.5 mm ten times a day significantly increases the mineralization process and bone healing (4). If the displacement of 2 mm and cyclically repeated daily over 10000 times, lead to inhibiting process of bone healing and pseudoarthrosis. On the movement of bone fragments affects interfragmentary compression in space. Compression of 20-57 kP to 1cm of bone surface that allows bone fragments merge directly, penetration of osteoclasts and osteoblasts and the formation of lamellae and osteon (7). These conditions allow primary bone consolidation. Minimum compression is required for the humerus, the middle of the tibia and the largest for femur (9).

The study of biomechanical characteristics of these external fixators on a physical model of the PVC pipe using mathematical and computer simulators showed that biplanar fixation is far more stable than uniplane (10). However, it was confirmed that uniplane fixation is easier and creates a favorable biomechanical conditions at the site of bone fracture healing, especially if they are made by convergent pins (11). Ilizarov's fixator is multiplane fixation, but its strength is dependent on the tension of thin wires, and provides good stability only in transversal plane. That is, each has its own indication of the fixator, and the choice of fixation should be based on their mechanical properties, geometric form and the potential of bone fracture healing, with a permanent simplification of treatment, which must remain sufficiently safe and acceptable to the patient. The main advantage of this study was the comparison of strength for four kinds of mostly used fixators in the only way possible– on the bone model. Any other comparisons would give a lot more questions than answers because of unacceptably large bias of other parameters that powerfully influence the results of the study.

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