ORIGINAL ARTICLE

Comparison of biomechanical stability of osteosynthesis materials in long bone fractures

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ABSTRACT

Aim To calculate stress and deformation under the force of pressure and bending in the dynamic compression plate (DCP), locking compression plate (LCP), selfdynamisable internal fixator (SIF) and locked intramedullary nail (LIN) in the models of juvidur, beef tibia bone (cadaver) and software of bone model simulator.

Methods Juvidur and bone models were used for the experimental study, static tests were performed with SHIMADZU AGS-X tester. CATIA software was used to create a 3D model for the SCA simulator, while software ANSYS to calculate the tension and deformation for compressive and bending forces. Stress and deformation analysis was performed with the use of Finite Element Analysis (FEA).

Results Weight coefficients of research methods were different (juvidur=0.3; cadaver=0.5; SCA Simuator=0.2), and weight coefficients of the force of pressure K_p=0.5 and bending forces in one plane K_1=0.25 and K_2=0.25 in another plane, the overall result on the dilatation of DCP, LCP, LIN and SIF on juvidur and veal cadaver models showed that the first ranking was the LIN with a rank coefficient $K_{U\text{-}LIN}$ = 0.0603, followed by the IFM with $K_{U\text{-}IFM}$ = 0.0621, DCP with $K_{U\text{-}DCP}$ = 0.0826 and LCP with $K_{U\text{-}LCP}$ = 0.2264.

Conclusion Dilatation size did not exceed 0.2264 mm, hence the implants fulfilled biomechanical conditions for the internal stabilization of bone fractures. Prevalence goes to the locked intramedullar nailing and Mitković internal fixator in the treatment of diaphyseal, transversal, comminuted fractures in relation to DCP and LCP.

Key words: osteosynthesis material, bone, software models, biomechanics

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INTRODUCTION

Extremities are most frequently exposed to injuries in everyday activities, falls, traffic accidents and in missile injuries. The incidence of limb injury in polytrauma is 58.6% (1). Long bone fractures on the lower extremities are present in 21.9% of traumatised patients (2), while fractures of the long upper extremities are present in 19% (3). The conservative form of treatment lost its primacy over the surgical treatment (4). For decades, the surgical form of osteosynthesis of the closed long-bone fracture is usually performed by internal fixation with the following: dynamic compression plate (DCP), locking compression plate (LCP), internal fixator by Mitković (IFM) and locked intramedullary nailing (LIN). Longstanding experience in clinical and scientific/research work has not yet set clear guidelines on the use of osteosynthetic material for the stabilization of long bone fractures (5). Further development of biomechanical research will probably lead to a concession in the use of osteosynthetic material (6,7).

The aim was to examine the calculation of tension and deformation under the force of pressure, and bending forces in the dynamic compression plates (DCP), locking compression plates (LCP), Mitković internal fixator (IFM) and locked intramedullary nail (LIN) on juvidur and veal cadaver models and software of bone model simulator.

MATERIALS AND METHODS

Study Design and Setting

The investigation was carried out at the School of Mechanical Engineering in Niš from January to June 2016 in order to calculate stress and deformation under the force of pressure and bending in the dynamic compression plate (DCP), locking compression plate (LCP), selfdynamisable internal fixator (SIF) and locked intramedullary nail (LIN) in the models of juvidur, beef tibia bone (cadaver) and software of bone model simulator.

Methods

Geometrically identical, anatomically shaped juvidur and bone models with diameter of 30 mm and the length of 100 mm were used for the experimental study. “The bone” was two juvidur parts at the distance of 10 mm, which were stabilized by tested osteosynthesis material. A ‘’medullar cavity’’ was created by drilling the juvidur bar. Models were manufactured in equal, controlled conditions. Such juvidur models provide identical biochemical conditions for all tests of the tested osteosynthesis materials .

Veal cadaver with diameter of 30 mm, length of 100 mm and medullar cavity of 16 mm were used for the experimental study. Osteosynthesis material (DCP, LCP, IFM and LIN) was placed under the same conditions, with two veal bones at the distance of 100 mm. The same manufacturer was used for DCP, LCP and LIN (manufactured by Narcissus, Ada, Serbia), while the other one was used for IFM (manufactured by Traffix Niš, Serbia). Tested osteosynthesis material was placed on juvidur and veal cadaver models; the DCP without locking and the LCP plates with 10 holes. The plates were placed on juvidur, that is, veal cadaver, with three screws on each side of “the fracture”, making a total of six screws per plate. The LIN, with the length of 200 mm, was placed in the “medullar cavity” of the juvidur model as well as in the medullar cavity of the veal cadaver with one proximal and distal screw. The same technique was used to place the IFM on juvidur and veal cadaver models. Special fixation clamps for proximal and distal part of juvidur and veal cadaver bone were made to provide more accurate positioning and fixation.

Static tests were performed with the usage of SHIMADZU AGS-X tester with the force of pressure increasing from 0 N to 500 N, and with the subsequent relief. Data and recorded diagram of the change in deflection were written in the software which was the integral part of SHIMADZU AGS-X tester. By dividing the maximum force with the total time, the increase in force per unit of time was obtained.

CATIA software was used to create a 3D model for the SCA simulator, while software ANSYS was used to calculate the tension and deformation for compressive and bending forces. Stress and deformation analysis was performed with the use of Finite Element Analysis (FEA). The tested osteosynthesis material was loaded by the compressive forces of up to 500 N and bending forces up to 250N. We tracked the force and deformation which occurred due to the force of pressure/compression/ or bending and on those bases, we evaluated stability.

Ranking of the DCP, LCP, LIN and IFM was carried out specifically for juvidur, veal cadaver and SCA simulator testing. The ranking was done by determining the minimum rank coefficient, obtained on the basis of the arithmetic mean (mean value) of dilatation in millimetres. The ranking was determined for two cases. The first one, an equal weight coefficient of arithmetic values (mean values) of dilatation for each type of load. The second one, different weight coefficient of arithmetic values including: weight coefficient for the pressure K_p=0.5; weight coefficient for bending in one plane K_1=0.25; weight coefficient for bending in another plane K_2=0.25. (6,7) Juvidur model was exposed to the same conditions, compression forces and lateral bending forces in one plane and lateral bending forces in other plane. This research showed that that the IFM had the smallest dilatation, 0.2007, followed by the DCP with 0.2602, LIN with 0.2719 and LCP with 0.5459.

The research on the software model in the stimulator showed that the LIN had the smallest dilatation with 0.1950, followed by the DCP with 0.1970, the IFM with 0.2238 and the LCP with 0.2394 (7).

Statistical analysis

On the basis of ranking of biomechanical stability of the tested osteosynthesis materials (LIN, DCP, LCP, IFM) for specific test methods (juvidur, veal cadaver, SCA simulator), the overall ranking of tested osteosynthesis materials was obtained. Overall coefficient rank for each osteosynthesis material and each testing method (SCA simulator, juvidur model; veal cadaver) was determined according to the following algorithm:

$$K_{u-i} = Min_j \; (K_p * \overline{X_p} + K_1 * \overline{X_{1i}} + K_2 * \overline{X_{2i}})$$

K_i – the overall result for each osteosynthesis material; i – LIN; DCP; LCP; SIF note of osteosynthesis material; j – JU - juvidur; TT – veal cadaver; SCA – SCA simulator;

$\overline{X_p}$ – arithmetic value of dilatation (mm) for the force of pressure; K_p – Pressure Coefficient;

$\overline{X_{1i}}$ –the arithmetic value of dilatation (mm) for the bending force in one plane; K_1 – coefficient of the bending force in one plane;

$\overline{X_{2i}}$ – the arithmetic value of dilatation (mm) for the bending force in the other plane; K_2 – coefficient of bending forces in the other plane.

Table 1. Biomechanical testing results

Rank*	Type of osteosynthesis material	Rank coefficient†
1	Locked intramedullary nail (LIN)	0.0603
2	Internal fixator by Mitković (IFM)	0.0621
3	Dynamic compression plate (DCP)	0.0826
4	Locking compression plate (LCP)	0.2264

*order of biomechanical stability of tested osteosynthetic materials;
†dilatation coefficient of tested osteosynthetic materials

RESULTS

The overall result of the study on the mechanical stability of osteosynthesis material (DCP, LCP, LIN and SIF) on juvidur and veal cadaver models and SCA simulator with weight coefficient test methods (juvidur = 0.3; cadaver = 0.5; SCA = Simulator 0.2) and weight coefficients of forces (pressure Kp = 0.5; bending in one plane K_1 = 0.25; bending in the other plane K_2 = 0.2, showed that the LIN had the smallest dilatation with a rank coefficient K_{U-LIN} = 0.0603 , followed by the IFM with K_{U-IFM} = 0.0621, DCP with K_{U-DCP} = 0.0826 and LCP with K_{U-LCP}= 0.2264 (Table 1)

DISCUSSION

Less invasive osteosynthetic material DCP, LCP, LIN, which is used for fracture stabilization has been widely used in clinical practice and nowadays, it provides new opportunities and challenges for modern surgical treatment of fractures (4,5). The plates, screws and pins themselves cannot completely solve all the problems that are encountered in the fracture repair. Bone healing requires a relatively stable environment, precise anatomic reposition and reliable internal fixation (6,7).

Florin et al. have conducted biomechanical tests of DCP, limited contact DCPlate (LC-DCP), LCP and internal fixation bars (CRIF-Formal VetFi) on long bones of horses (8). Studies have shown that DCP, LC-DCP and LCP constructions provide good biomechanical stability and support loads in one cycle (8). Taking into account the biomechanical properties of DCP, LC-DCP and LCP constructs, they have not found statistically significant differences in the examined implants. In addition, they prefer the LCP implants because of the high yield strength, high stiffness under high-load application, and the least movement at the fracture line (8).

Jiang and associates conducted biomechanical tests on the comminuted fractures of the long femoral bone. The stabilization of the fracture was performed with the use of two kinds of plates: a newly designed locking compression plate (NLCP) and a locking compression plate (LCP). The fracture repair was monitored by computed tomography (CT). After the analysis of the obtained results, the advantage was given to the NLCP plate which gives better biomechanical stability in all three levels in cases of comminuted long bone fractures (9).

When a person weighing 70 kg falls to the ground from a standing position, the energy is about 500J. Eccentric muscle contractions and deformations of soft tissues have the ability to absorb energy and prevent bone fractures in the insignificant, slight falls of young people. Muscles and ligaments of older people are unable to resorb the same energy (10).

Tsutsui et al. conducted biomechanical tests on 15 cadaveric forearms. They stabilized the fracture with the use of the LCP plate. They compared the changes in biomechanical and radiographic properties under cyclic axial loading between groups; one where two rows of distal screws were used, and one where only one row of distal screws was used (11). Cyclic axial compression test was performed (3000 cycles; 0-250 N; 60 mm/min) to measure absolute rigidity and displacement, after 1, 1000, 2000 and 3000 cycles, and values were normalized relative to cycle 1 (11). Biomechanical and radiographic analyses demonstrated that two rows of distal locking screws in the DSS procedure conferred higher stability than one row of distal locking screws (11).

The trauma accounts for about 11% of the diseases in the world, and the fractures are the most presented in trauma. When it comes to the choice of implants, the one that provides micro-movements at the fracture site, as the micromovements stimulate the callus formation, should be used (12). Researchers claim that the future of osteosynthetic material is in biodegradable plates (13). The authors created Auxetic Polymeric Bone Plate, which can be used as an internal fixator for bone fracture (13). It provides micro-movement due to its counter intuitive behaviour and has the potential to reduce the effect of stress at the fracture site and allow the same range of motion as that of natural bone (13).

Augat et al. have accomplished good results in the treatment of the distal tibia fracture with intermedullary implants when two screws, preferably in crossed configuration, are placed in the distal fragment (14).

The LCP and DC plates rely on completely different mechanical principles in order to ensure the fracture stability and thereby provide different biological environments (15). The LCP plates display good results in metaphyseal fractures, osteoporotic bones and bridging of multifragmented, comminuted fractures as they reduce bone tension with bridging, while DCP plates can still be the method of choice used to stabilize diaphyseal fractures that require perfect reposition (15).

Osteosynthetic material must keep a fracture stable in the internal/external rotation. The internal torque sufficient to ensure adequate stability in the femur of the infant cannot be reliably achieved with the use of 4.5 mm cortical screws (16). The second limiting factor is poor bone cavity of the distal fractural fragment. The construction of LCP plates is significantly more resistant to compression when compared to DCP plates (16).

In a series of 25 calves, LCP was examined in the treatment of closed diaphyseal femur fractures (17). Apart from clinical signs, the fracture repair was monitored radiographically (17). The LCP wedge that was locked in this study was associated with a good prognosis for surgical treatment of femoral fractures regardless of fracture site (17).

Examining the biomechanical stability of a 3.5mm cortical screw that was used to stabilize DC, DCP and LCP to axial forces showed that the screws in the plates maintained physiological loads of the extremities (18). The LCP plate with neutrally placed screws that maintain the planned intrafragmentary gap allows the movement of the fragments up to 15% if the intrafragmentary crack is up to 2 mm (18); this could not achieve with DC and DCP plates (18).

In conclusion, the examined osteosynthesis material has shown that the dilatation size did not exceed 0.2264 mm, hence the implants fulfil the biomechanical conditions for the internal stabilization of bone fractures. A good technical solution, internal fixator by Mitkovic, enables fast placement, minimal trauma of soft tissue and deperiostation, which gives it the advantage of stabilizing the *diaphyseal long bone fractures* compared to the examined ones.

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TRANSPARENCY DECLARATION

Conflicts of interest: None to declare

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