PERIODICUM BIOLOGORUM
VOL. 112, No 1, 59–62, 2010

UDC 57:61
CODEN PDBIAD
ISSN 0031-5362

Original scientific paper

Applicability of bovine tibia as a model in research on various osteosynthesis techniques

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Key words: bovine bone, human cadaver bone, osteosynthesis, biomechanics

Received March 16, 2010.

Abstract

Background and Purpose: *The main problem in experimental research in traumatology and orthopedics is unavailability of a large number of samples of human origin. In this research, standard and modified osteosyntheses were performed on bovine tibia to determine whether bovine tibia can be used as a model in biomechanical research on two or more methods of osteosynthesis.*

Materials and Methods: *Investigations were carried out on six preparations of cadaveric human tibia and on six preparations of bovine tibia with the use of device for static and dynamic research on long bone model. The bones were artificially broken and then osteosynthesis was performed on them in two ways: applying the standard method and the modified method with bone cement. The aim of these investigations was to determine the size of the axial force and torsion moment that can be exerted to apply static and dynamic loading on the macerated cadaveric tibia and bovine tibia without breaking the bone or causing its permanent deformation.*

Results: *Investigations conducted on preparations of bovine tibia and cadaveric human tibia showed that there was not even minimal deformation of the bovine tibia in both standard and modified osteosynthesis. There was no shift in torsion angle at all with all three values of torsion moment applied in these investigations. This result was obtained in both standard and modified osteosynthesis. The results showed that in both bovine and human preparations the loosening occurred sooner when standard osteosynthesis was applied.*

Conclusion: *In conclusion, the bovine bone has good potential for use as material for biomechanical experiments.*

INTRODUCTION

In operative treatment of a bone fracture, the main goal is to ensure permanent stability of bone fragments while simultaneously allowing active movements of the muscles and joints of injured extremity until the fracture is completely healed *(1, 2)*. It is accomplished by application of standard technique of osteosynthesis according to the AO principles *(3, 4)*, which includes two methods: the AO method of interfragmental compression and AO method of placement of the guide wire. Unlike the method of interfragmental compression, the method of placement of the guide wire cannot result in absolute stability of bone fragments, which results in secondary healing of the fracture and development of a smaller or greater callus in the area of fracture line *(4, 5)*.

As interfragmental compression is achieved, bone fragments are brought together and friction is increased, which neutralizes mechanical forces that impede fracture healing. Neutralization of bending, shearing and torsion significantly increases the stability of osteosynthesis *(6)*. Provided that local circulation is ensured, primary bone healing occurs without callus formation that can be seen radiographically. Interfragmental compression may be static and dynamic.

In static interfragmental compression the implants are placed while tensile force is applied on smaller or larger portion of bone fragments. It is applied by a lag screw, single or dual tension band plate and external fixator which act to compress bone fragments.

In dynamic compression, the fracture line is compressed with tension band implants and the loading is applied by the same forces that occur on the fracture site when performing normal activities. The tension band plate that is placed on the tension part of the fracture counteracts tensile forces, converting them into compression forces at the fracture site during active movement and loading *(4, 7)*.

Since surgical techniques of osteosynthesis are complex and the choice of optimal treatment method is clinically significant, experimental research on various methods of osteosynthesis is a necessary precondition for introduction of a certain method into clinical practise *(8)*. The main problem in experimental research in traumatology is unavailability of a large number of samples of human origin.

Therefore, standard and modified osteosyntheses were performed in this research on bovine tibia to determine whether bovine tibia can be used as a model in biomechanical research in two or more methods of osteosynthesis.

MATERIALS AND METHODS

Sample. Investigations were carried out on six preparations of cadaveric human tibia and on six preparations of bovine tibia. Identical investigations were conducted on both groups of preparations. The bones were artificially broken and then osteosynthesis was performed on them in two ways: applying the standard method and the modified method with bone cement. Artificial fractures were oblique and the bones were broken on the same anatomical site. Osteosynthesis was then performed with identical metal implants and using the same number of screws. On the preparations obtained in this way, biomechanical investigations were done using a specially designed device.

A device for static and dynamic research on long bone model (Figure 1a, 1b) was designed at J.J. Strossmayer University of Osijek, Faculty of Electrical Engineering. It is based on original instructions of American dynamic simulator »Digitax«, original instruction of German impulse generator »Max« and Croatian Ministry of Science software package of the programme Statistica 6.0 used at J.J. Strossmayer University of Osijek. A synchronous motor produced by »Končar« Zagreb is used in this device.

The device is designed to perform cyclic load on the bone model, whereby the size of the force, force direction and number of cycles in a time unit change. It was designed for investigations on humerus, femur and tibia. Default conditions for programming are biomechanical conditions in which these bones function biologically. The designed device simulates both mechanical and biological loading on these bones in various movements the human body performs.

The aim of these investigations was to determine the size of the axial force and torsion moment that can be exerted to apply static and dynamic loading on macerated cadaveric tibia without breaking the bone or causing its permanent deformation. Deformation was measured at one point. Deformation caused by torsion moment was dominant: angle shift at a distal end of tibia, more precisely at a lower internal malleolus. Torsional effect of the load was simulated with a complex synchronous device which received impulses from a special device where frequency and amplitude were changed, and the final result of regulation was torsion moment [Mt]. The results of angle shift of defined bones were measured with the angle of deflection, and defined angle was determined by reflection of the laser beam on the screen.

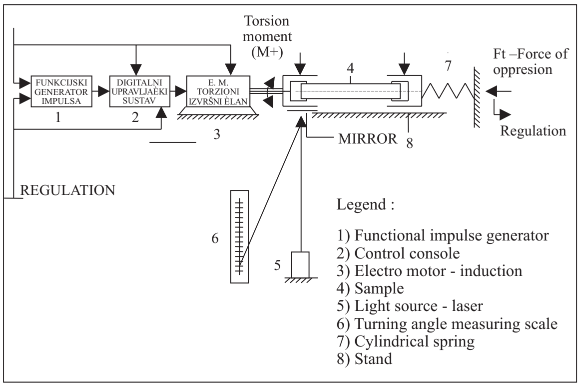

Figure 1a. *Schematic presentation of a device for static and dynamic research on long bone models.*

Figure 1b. *Picture of the device for static and dynamic research on long bone models.*

The preparations underwent investigations under static and dynamic complex load. Static investigations included two types of loads: axial or longitudinal force and torsion moment. Axial load was 400.0 [N], and three values of torsion moment were observed: 2.94 [Nm], 3.92 [Nm] and 4.90 [Nm]. In dynamic load, axial force was 100.0 [N] and regularly interrupted torsion moment 3.0 [Nm].

The result of this combined axial and torsion load was dominant torsion deformation. As the torsion moment was increased, there was linear progression of deformation and of the torsion angle shift.

RESULTS

Static loading. When static torsional loading was applied on cadaveric human preparations of tibia that were treated both by standard and modified osteosynthesis, the obtained results showed that the angle of torsion on average increased linearly as the external loading was increased. Standard osteosynthesis showed greater shift of torsion angle in the range from 0.1 do 0.25 degrees in relation to modified osteosynthesis, as well as greater deformation or less rigid osteosynthesis of fractured bone fragments under the same torsion moment loading (Figure 1).

Unlike on human preparations, investigations conducted on preparations of bovine tibia showed that there was not even minimal deformation of the bovine tibia in both standard and modified osteosynthesis. There was no shift in torsion angle at all with all three values of torsion moment applied in these investigations. This result was obtained in both standard and modified osteosynthesis.

Dynamic loading. The results for dynamic loading on the preparations of bovine tibia and cadaveric human tibia after standard and modified osteosynthesis are shown in Figure 2. The value obtained by measuring the torsion angle shift was plotted on the ordinate axis, while the duration of the loading up to the point when loosening of the osteosynthesis, defined by the measured torsion angle shift first occurred, was plotted on the abscissa. Since the time elapsed before loosening in modified osteosynthesis occurred was relatively long, time duration for defined torsion angle shift was given in logarithmic scale.

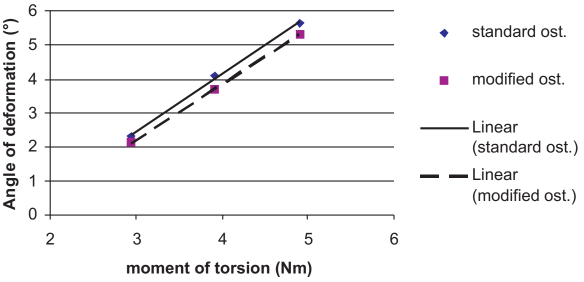

Figure 2. *Angle of deformation of human samples during static torsional loading.*

It was noticed, that in all diagrams, the functions presenting the results obtained on all samples had similar forms: one part was a straight line, which changed into similar curve lines as the loosening started. The moment when the torsion angle shift was more than 0.2 degrees was determined as safety threshold. The difference was noticed in the length and position of lines, as well as in the length of curved parts of the function (Figure 3).

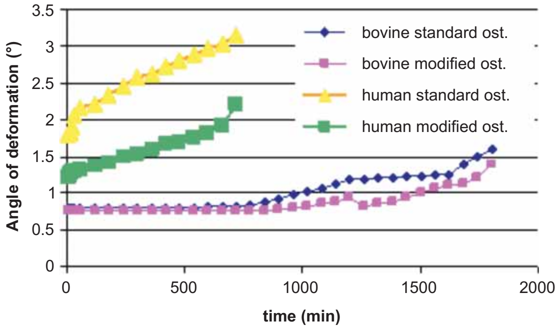

Figure 3. *Angle of deformation of human and bovine samples during dynamic torsional loading.*

The results showed that in both bovine and human preparations loosening occurred sooner when standard osteosynthesis was applied.

In standard osteosynthesis, torsion angle shift of more than 0.2 degrees occurred already after 50 seconds and reached its maximum after 50 minutes. In modified osteosynthesis with bone cement the torsion angle shift of more than 0.2 degrees first occurred after 120 minutes and after 1000 minutes it was only 0.7 degrees.

Mathematical analysis of differences between standard and modified osteosynthesis obtained in this experimental research is presented in Figures 4 and 5. In standard osteosynthesis of tibial fracture, the greatest strain occurred in the small part of the screw neck immediately below the head, while the strain almost did not occur in screw heads. The space between the plate hole and the cortex in modified osteosynthesis was filled in with bone

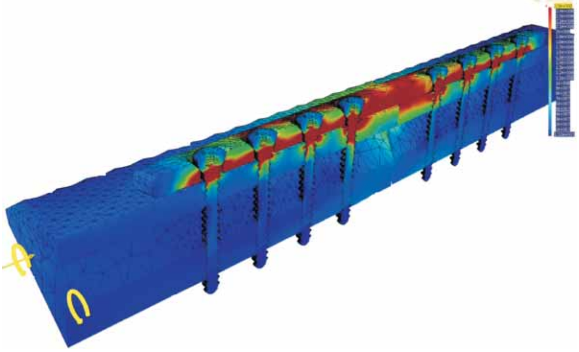

Figure 4. *Numeric model of longitudinal vertical section in common osteosynthesis on macerated cadaveric fractured tibia shaft across plate, bone cortex, head and body of cortical screw.*

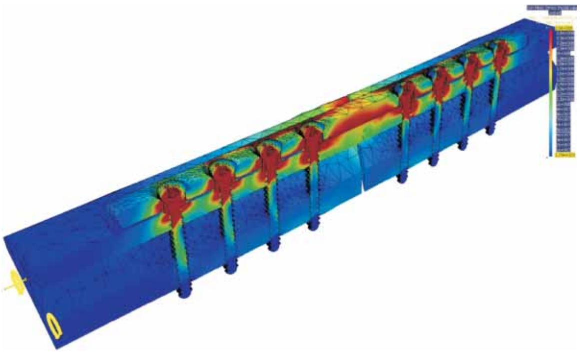

Figure 5. *Numeric model of longitudinal vertical section in modified osteosynthesis on macerated cadaveric fractured tibia shaft across plate, bone cortex, head and body of cortical screw.*

cement, which ensured the firm connection between the screw head, plate and the cortex below the plate. This firm system resulted in even strain distribution, which occurred in screw heads and necks as well as in the cortex around the screw body.

DISCUSSION

Such result was obtained due to prominent thickness of the cortex and short body of fresh bovine tibias used as samples, high bone density, large contact surface at fracture line, and properly performed osteosynthesis that resulted in high stability of fracture fragments.

Differences between human and bovine bones are small but crucial for further research. A comparison of relative strength and toughness of human and bovine bone showed that even though human bone is significantly weaker than bovine bone relative to its strength, the toughness of human and bovine bone was roughly similar, but it is hard to say which was tougher. Absolute toughness of bovine bone is greater than in human bone. Logitudinal strength of bovine bone compared to longitudinal strength of human bone was approximately in the ratio 1.5 to 1 *(9)*. Although human and bovine bones are different, the effect of thickness on human bone fracture toughness can be estimated using bovine bone, assuming the thickness effect is independent of microstructure. The fracture toughness of bovine bone relative to the human bone ranges from 1.08 to 1.66 *(10)*. It is also important to understand the role of microdamage on the failure behavior of the whole bone at any anatomical site. The surrounding trabecular network and the cortical shell also play a role in whole bone fracture *(11)*. It has been proposed that although human bone is mechanically weaker in bending and tension than bone of most other animals, its osteonal structure has adapted to prevent crack growth, thereby extending bone fatigue life *(12)*.

In conclusion, the bovine bone has good potential for use as material for biomechanical experiments (*2*) since it is easily resourced, relatively inexpensive and non toxic.

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