UNIVERSITY OF MEDICINE AND PHARMACY CRAIOVA

ABSTRACT OF PhD THESIS

SURGICAL TREATMENT VALUE IN HUMERAL SHAFT PSEUDARTHROSIS
FEM EXPERIMENTAL STUDY

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Content

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Since ancient times, surgeons were concerned by the delay or absence of fractures consolidation and basic principles of fracture treatment were mentioned since antiquity. Over the centuries, there have been imagined many treatment methods, in an attempt to successfully solve these unwanted and difficult complications that may arise in fractures treatment.

At the beginning of the twentieth century fixation takes place increasingly more important in fracture and pseudarthrosis treatment. Fixation methods are then developed at rapid, providing varied extremely useful support in pseudarthrosis treatment.

The paper is structured in two parts: the general and original.

The general part is divided into 5 chapters and the original into 2 chapters.

Chapter 1 gives data on the anatomy of the arm. There are presented one by one: skeleton, muscles, fascia, vascularization and innervation of the arm. Then topographic anatomy data follows and it is noteworthy that the topographically upper epiphysis of the humerus belongs to the shoulder, and lower epiphysis, to the elbow region. In turn, the shaft has three segments: upper, middle and lower.

Chapter 2 presents the functional anatomy of the arm. Scapular kinematics unit belt - shoulder - arm has five joints, three of the scapular belt and two of the shoulder. The three joints of the scapular belt are: sternoclavicular, acromioclavicular and scapulothoracic. The shoulder has two joints: a classical (shoulder joint itself or scapulohumeral joint) and one accessory (the second joint of the shoulder).

Kinematic unit shoulder belt – shoulder – arm biomechanics is complex. To understand it is presented, one by one, the role of each of the five types of joints and their movements and finally a full summed mechanisms that allow movement. The arm and shoulder muscle groups are described, along with their actions and it is emphasized that arm biomechanics can be judged only in the context of kinematic unit shoulder belt - shoulder – arm, unit that provides freedom of movement necessary to perform successfully the multiple functions of upper limb.

Chapter 3 is reserved for normal arm exam, both clinical and radiographic. Here are presented the types of x-rays, patient position for the correct execution and visible marks on each view.

Chapter 4 details the terms of issue of this paper: pseudarthrosis. There are exposed one by one: definition, classification, ethiopathogeny, the role of vascularization, histology, clinical exam, radiology and scintigraphy.

Humerus shaft pseudarthrosis is defined as *the absence of fracture consolidation after the usual interval of consolidation of 2 to 3 months after the accident, in the presence of small abnormal movements and a very discreet radiographic callus*.

There are given several classifications, depending on the situation of the fragments, mobility and distance between fragments, fragments vascularization, skin condition and pathological classification.

Pseudartrosis *causes* are grouped according to trauma condition, patient general state, local causes and treatment errors.

Local vascularization is described in the phases of consolidation after fracture, highlighting the role of local growth factors. In hypervascular pseudartrosis, which are most commonly encountered disorders, callus formation stage is normal, but the bone formation does not occur, just by maintaining abnormally congestion, consequently fragments remained uneven between them. Callus is often monstrous, osteoformation reaction was excessive and giving the impression of a sclerosis of the fracture ends. Aspect is at the beginning of nonunion false, because there is no established sclerosis, only osteoid tissue impregnated with plenty of calcium, which intimate surrounds decalcified ends.

Histopathology describes macroscopic and microscopic changes depending on the type of nonunion and its development phases. *Clinical examination* analyzes presence of the following signs: pain, swelling, abnormal mobility, disability.

Radiography is the revealing exam and it may show: the lack of continuity between the fragments with the presence of a clear space between fragments, misalignment or bending, densification of bone extremities (in atrophic and avascular pseudarthrosis), thickening of bone extremities (in hypertrophic or hyper vascular pseudarthrosis), obstruction of medullary canals, sometimes a discreet insufficient callus, relations between fragments and fixation material (plates, rods, wires, screws, staples) and relations between fragments and possible graft, and sometimes in a seemingly voluminous callus, seen by radiographs made in two-three positions, the path of not consolidating surprises. This is what is called the trajectory of nonunion in callus;

often it is only translated clinically by functional impotence and pain, without abnormal movement in the fracture site.

Scintigraphy examination, which lists the types of scan patterns, may be useful in the pseudarthrosis diagnosis.

Chapter 5 - Treatment of humeral shaft nonunion - consists, depending on the anatomic type of nonunion, in:

- in the fibrous pseudarthrosis: osteoperiostic decortication followed by plaster immobilization or, more frequently, compression plate fixation or with intramedullary nail;
- in fibrosynovial pseudarthrosis: osteoperiostic decortication followed by compression plate osteosynthesis or locked intramedullary nail with reaming. These are supplemented or not with graft osteoplasty.
- in the floating pseudarthrosis: osteoplasty with autogenous graft shaft (fibula) or allogenic graft (bone bank) and fixation with plate or intramedullary nail;
- in infected pseudarthrosis: two-stage treatment. The first is the removal of osteosynthesis material completely, cleaning the site and bacteriological sampling, fixation with external fixation and treatment with antibiotics. Away from this time, given a favorable evolution of infection, surgical revision and fixation by one of the methods described above.

Treatment goes through several stages to be followed. There are presented the approaches (lateral, anterior, posterior and medial) and the means of fixation (plate and screws, intramedullary with its variants, external fixator). Special attention is paid to septic pseudarthrosis treatment.

The end of this chapter presents new methods used in addition to traditional methods of fixation, new substances in medical practice, such as BMP-7, recombinant human morphogenetic protein (rhBMP-2) and mesenchymal stem cells.

Chapter 6 presents the cases operated between 1963-2012, respectively 67 cases of pseudarthrosis in 57 patients. Courtesy of Academician Professor Dr. Nicolae Gorun, it was taken his casuistry, including cases operated from 1963 to 2005. In cases operated between 1996 - 2012 the author was second or prime operator.

Depending on the fracture treatment leading to nonunion there were registered 20 cases after orthopedic treatment (29.9%) and 47 cases after surgery (70.1%). The median age was 50 years;

the minimum was 18 years and the maximum 82. Distribution of cases by age group shows great social importance of this condition, most cases were registered during the active life (25-54 years).

Distribution of cases according to the location of the site of nonunion, shows that the most frequent site is the middle shaft. Types of fixation used were as follows:

- plate osteosynthesis (with 4 screws: 4 cases; with 6 screws: 26 cases; with 7 screws: 8 cases; two cases using a "Y" plate; with 8 screws: 19 cases; with 9 screws: 2 cases).

In 19 cases we did not appeal to compression. When compression was achieved, in 30 cases was made on the upper fragment, and in 10 cases on the lower.

- nailing fixation (antegrade K nail: 2 cases; retrograde K nail: 1 case; antegrade Ender rod: 1 case; static locked antegrade intramedullary nail: 1 case);
- 2-pin intramedullary fixation: 1 case;
- graft fixation with cortical tetralateral: 1 case;
- fixation with external fixator: 1 case.

In two cases the metal fixation resumed, in one case it was necessary to supplement the K nail introduction, and in another case it was necessary to replace with one thicker K nail.

In 26 cases it was necessary osteoplasty.

There are presented some of the selected cases operated, accompanied by pre-and postoperative radiographic images and microscopic images of tissue taken from the site of nonunion.

Chapter 7 presents the experimental study of humerus shaft pseudarthrosis with finite element method. In humeral shaft pseudarthrosis, how to make metal plate fixation of bone fragments support plays an important role in the recovery and healing of bone tissue. This is because during installation, it can cause local tension too high or too low, tension that require bone structure (living tissue) to respond to these requests by increasing or decreasing bone density. Another important factor is that the metal plate change tension "path", so around the cortical plate tensions are lower, leading to bone resorption. By mathematical simulation (FEM), the material properties of cortical and cancellous bone can be determined by bone density and thus to calculate the risk of fractures.

Currently it is known bone recovery mechanism and the factors that contribute to faster healing. There have been studies on mathematical models that highlight the link between stress and bone density values, but we do not know exactly the limit values.

In this study, finite element method was used to determine the state of stress of the humeral cortex, which is made when fixing a steel plate provided with six fixing holes and compression (installation) is provided by a Müller compactor. They considered three cases of fracture: resection parallel straight (humeral shaft angle of approximately 90 °), parallel oblique resection (angle of approximately 75 °) and resection in "steps opposite scale", comparing the states and distribution of stress and strain. The study was conducted with the computer program ANSYS finite element V14.

The method was developed based on the classical equations known in strength of materials, applicable for objects with constant section, for which, knowing the dimensions and material properties can be determined response under the action of known tensions.

In fact, the method involves generating a mathematical model, three-dimensional, where there are known the length, area, volume bodies, by reporting lines points to a global coordinate system (the body is positioned to a known reference). To each body of the studied structure is assigned a material with a minimum characterization by modulus of elasticity (Young's modulus), transverse contraction coefficient (Poisson's ratio) and material density. Is necessary to know the operating conditions, consisting of information on how to support (fixing, bearing) the structure and tensions of the application to which it is subject.

Thus, for the experimental study were the following steps: Step 1. Geometric model; step 2. Finite element model; step 3. Boundary conditions; step 4. Solving system and interpretation of results.

In the geometric model, metal plate, Müller compactor and screws were measured with simple devices (like calipers); virtualizing complex geometry of the humerus, which is variable in cortical thickness and irregular shapes requiring performance of CT transverse different axial increments, depending on the complexity of bone surfaces. External surface of the humerus was considered as rigid body. Corresponding contour lines of the internal surface of cortex were introduced in ANSYS DM and provided the humerus geometric model generation with variable cortical thickness. Contour lines were simplified; their number was reduced, while keeping sufficient enough to allow obtaining accurate cortical thickness. These areas, together with the external surface for further processing, especially in the humeral shaft, generated geometric model for the humerus.

For virtualization of the geometrical model of fixation plate, there were measured on a physical model dimensions and geometry was obtained by ANSYS Design Modeler program, by specific commands. In the generation of the model was considered the creation of regular areas that will then allow mesh with hexahedral elements.

Similarly was done for Müller compactor, consisting of a perforated body that is attached to the humerus, a guide cylinder and a hexagonal screw. These models were then placed in a common basis for their assembly and set an initial relative position. All these geometries were introduced in one base and plate with compactor were positioned on the external side of the humerus, so like to be in a stable position of contact with the humerus. After set of relative initial position to the humerus, in the region of half plate board, there was done a fracture (resection) of the humeral shaft, width 2 mm, with 3 different forms:

- parallel surfaces which have a straight orientation (90 °) to the longitudinal axis of the humerus;
- parallel surfaces which are inclined (at an angle of 15 °) to the longitudinal axis;
- fracture (resection) surfaces arranged in "steps opposite scale". Based on the above geometric models were generated finite element models for all components that have been taken into account in this study.

Material properties used were taken from the literature: fixing plate, compactor elements and screws are stainless steel (Young modulus E = 186000 MPa and Poisson's ratio, transverse contraction coefficient of 0.3); for humerus material E = 17000 MPa and the rate of contraction (Poisson) of 0.3.

Each of the three study mathematical models were solved in four steps of loading. Loads or boundary conditions are identical for the three models and consist of:

1. placing two screws, one that secure the metal plate and a second one fixing the compactor;
2. insert the second screw into the metal plate;
3. insert the third screw into the metal plate and bone;
4. imposing of a translation movement by rotating compactor screw;

5. after a maximum movement, insert of the fourth screw in the plate and bone.

The results were shown as color maps with equivalent stress distribution, maximum principal stress, compression stress, displacement distribution, contact resection area and developed pressure friction.

In case of straight resection, the two bone segments were not in contact over a large area, but after the final step, the contact is closed on the entire section, the pressure is not uniform, being eccentric.

In case of 'in steps' resection, even if the contact between the two sections was not achieved at the end of step three, after compactor action, sections contact was done, and quite uniform.

In case of oblique resection calculations after load step 3 are similar to the case of straight resection. The results show that in this case there is no contact between the surfaces before using compactor, making a uniform game between surfaces.

Each model obtained at each stage of study, and conclusions are largely illustrated with color images.

The analysis of experimental data gives the following conclusions:

- the shaft tensions at the humeral shaft are beneficial for restoring humeral bone;
- use of compactor increases tension around the fixation cortical screw;
- finite element model provided comparable results provided by other authors;
- fastening screws closer to the fracture, result in the removal from the adjacent bone, so after using compactor, plate fixation should be done starting with the most far screw;
- at the end of compaction the common state of structures is recovered, as bone is working as a whole, which recommends compactor use;
- the most uniform contact was obtained for step resection and worst for oblique resection.
- it was noted that the use of a tensioning force of 100 N, determine acceptable bone tension (7-10 Mpa)

The paper concludes with an extensive bibliography.