

Innovative Device for Surgical Treatment of Acetabular Injuries

Mirzaev Sh. H.¹, Gaipov Z. A.^{2*}, Dursunov A. M.³

¹PhD, Head of the Department of Traumas` Consequences of the Republican Specialized Scientific-Practical Medical Center of Traumatology and Orthopedics., Tashkent, Uzbekistan

²Doctor of the Department of Traumas` Consequences of the Republican Specialized Scientific-Practical Medical Center of Traumatology and Orthopedics, Tashkent, Uzbekistan

³DSI, Senior Researcher, Department of Traumas` Consequences of the Republican Specialized Scientific-Practical Medical Center of Traumatology and Orthopedics, Tashkent, Uzbekistan

Abstract The study presents the results of experimental research aimed at evaluating the mechanical properties, structural reliability, and functional performance of an innovative device designed for the surgical treatment of acetabular fractures. The device, representing a modified clinic plate with enhanced fixation elements, was tested using a complex biomechanical protocol in the laboratory of structural strength and seismic resistance of the Institute of Mechanics and Seismic Resistance of Structures of the Academy of Sciences of Uzbekistan. A test specimen simulating comminuted acetabular fractures was constructed, incorporating both bone components and the newly developed fixation plate. Two strain-gauge displacement sensors were calibrated and installed to record micro-movements under controlled axial compression. Mechanical loading was performed on a UIM-50 universal testing machine with stepwise increases in compressive force. Experimental analysis demonstrated that the device ensures stable elastic behavior under loads up to 33.0 kgf, with the total deformation not exceeding 0.48 mm and without any residual displacement. Further load escalation resulted in the development of plastic deformation in the bone-implant system, indicating the structural limits of the device and defining its operational safety range. A load of 54.0 kgf led to direct tibial contact with the acetabulum and deformation of the implant. The results confirm that the innovative acetabular fixation plate possesses sufficient mechanical strength, adequate rigidity, and reliable stabilization capacity under physiological loads. These findings support its clinical applicability for the management of complex acetabular fractures and justify its introduction into surgical practice.

Keywords Acetabular fractures, Internal osteosynthesis, Clinical plate, Additive technologies

1. Introduction

Due to the rapid urbanization of society, a steady increase in pelvic and acetabular injuries is observed in the structure of modern trauma. Among the most severe musculoskeletal injuries in the structure of polytrauma are injuries to the pelvic ring and acetabulum, which occur in up to 10% of all trauma patients. Acetabular fractures, accompanied by displacement of fragments and hip dislocation, account for 7-16% of all pelvic fractures, according to some researchers. The demographic structure of this type of injury is dominated by individuals of working age, primarily men, indicating the socioeconomic significance of this problem [1,2,4].

A vast number of surgical treatment options for acetabular fractures have been developed, described in the literature, and implemented, but the issue remains unresolved. It has

been noted that the disability rate for patients undergoing surgery is almost three times lower than for those treated conservatively [3,5].

Due to the variety of acetabular fracture types, data regarding the choice of surgical treatment method are highly controversial. However, timely restoration of hip joint anatomy is essential for the subsequent functional prognosis. Therefore, we prefer surgical correction of fragment displacement to achieve congruence of the articular surfaces. Late complications of acetabular injuries (aseptic necrosis of the femoral head, development of heterotopic ossification, etc.) are generally associated with poor fracture repositioning [6,9,10].

Numerous studies have documented the undeniable advantages of open osteosynthesis of the acetabulum, which allows for precise repositioning and rigid fixation of fragments, which positively impacts both immediate and long-term treatment outcomes. Moreover, adequate repositioning and stabilization of fragments is achieved with a surgical approach

* Corresponding author:
dr.z.gaipov@gmail.com (Gaipov Z. A.)

as close as possible to the fracture site. This minimizes trauma to adjacent soft tissues. Despite the steadily increasing incidence of fractures, internal osteosynthesis for complex acetabular fractures has been implemented in only a few large trauma centers. One of the main problems is the delay in patients' admission to specialized centers for osteosynthesis [7,8].

Purpose of the study. Study of mechanical properties of the clinic plate.

2. Materials and Methods

The closest in technical essence is a fixator for fractures of the acetabulum, containing a curved plate with fastening holes for screws, characterized in that, in order to ensure one-stage restoration of the congruence of the articular surface and strong fixation of fragments, the plate is made in the form of a polygon with curved sides and forms a conical surface (SU, A.s. No. 1671280, A 61 B 17/58, 23.08.91).

This device for treating acetabular fractures is designed to provide stable and rigid fixation of bone fragments in comminuted fractures and to ensure congruence of the various sections of the acetabulum. The device comprises a gently curved arcuate plate with mounting holes for screws. Along the edge of the minor arc, the plate has four equally spaced, 90-degree triangular pins with a base size of 1.5 mm and a height of 3 mm for fragment fixation. In the center of the major arc, a 15x25 mm bar is positioned at an angle of 100 to 130 degrees with mounting holes for additional fixation to the pelvic bones. At the ends, ear-shaped bends with a radius of 10 mm, positioned at an angle of 125 to 130 degrees, provide secure fixation to the pelvic bones.

The device is easy to use and improves the reliability and stability of fixation in the treatment of acetabular fractures. It is recommended for widespread use in clinical practice.

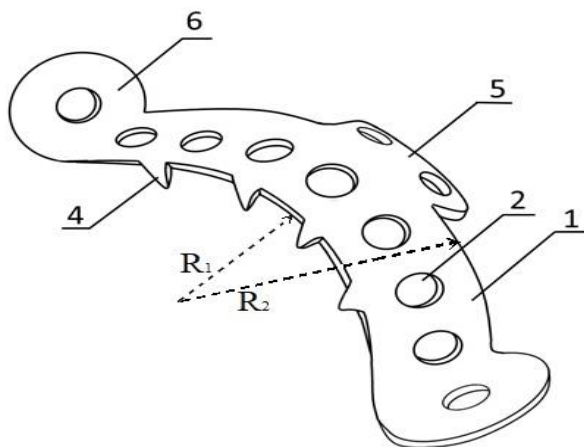


Figure 1. Schematic representation of the innovative acetabular fixation plate with anatomical curvature, multiple fixation openings, and reinforced structural elements designed to ensure stable congruence of acetabular fragments

During 202210 patients received treatment in the department fractures and fracture-dislocations of the

femoral head with fractures of the acetabulum. MThere were 7 men and 3 women. All patients underwent radiography, Doppler ultrasonography, EMG, laboratory tests (complete blood count and urine analysis, coagulation profile, blood biochemistry, etc.). In addition, MSCT was performed in 9 patients. In 8 patients, acetabular fractures were reduced with femoral head dislocation reduction and acetabular plate osteosynthesis. In 2 patients, acetabular fractures were reduced with femoral head dislocation reduction and acetabular plate osteosynthesis were performed.

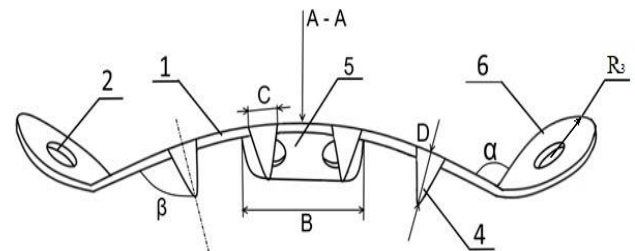


Figure 2. Illustration of the acetabular fixation device in assembled position showing the placement of screws, angular arrangement of fixation tabs, and the overall configuration of the plate relative to the acetabular surface

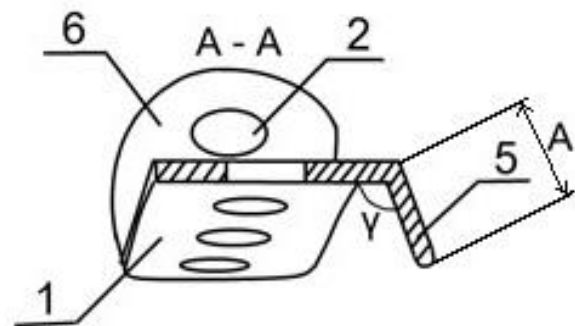


Figure 3. Cross-section A-A demonstrating the structural profile of the fixation plate, the thickness distribution, the fixation pin geometry, and the interaction of the implant with the acetabular cortical bone

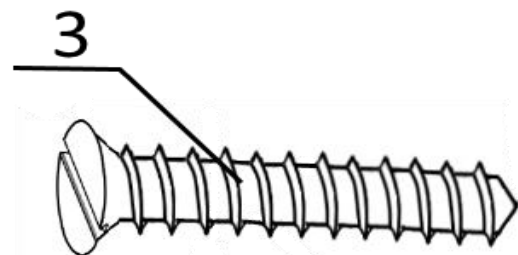


Figure 4. Design of the bone fixation screw used with the acetabular plate, showing thread geometry, core diameter, and head configuration intended for secure osteosynthesis

A bone sample near the acetabulum, containing multiple fractures, was used as a specimen for the study. A device for treating acetabular fractures was also installed in this area (Fig. 5).



Figure 5. Test sample

The specimen consists of two parts: a bone section near the acetabulum, where multiple fractures are present, and a section of the tibia, connected by a steel cable that ensures their joint alignment. A device for treating acetabular fractures is also installed in the same location where the multiple fractures are present. The device is secured with four screws located along the length of the plate and two screws located vertically in the center of the plate, using special holes for their attachment. Figure 3 shows the method for connecting the specimen parts for testing.



Figure 6. Parts of the test specimen

Since the specimen being studied consists of two parts, rigid fixation of one area under study is necessary. To fix the bone fragment near the acetabulum, this section is immersed in a solution containing alabaster. Then, the locations for the recording strain gauges are determined and installed. The strain gauges are positioned so that each one records displacement values within its own surface and is oriented perpendicular to the tibial axis. The installed strain gauges do not adversely affect the specimen under study. Before installing the strain gauges on the specimen, calibration is required for the strain gauges recording the relative displacement of the parts.

Figure 7 shows the test sample with a smoothly curved plate and installed displacement sensors.

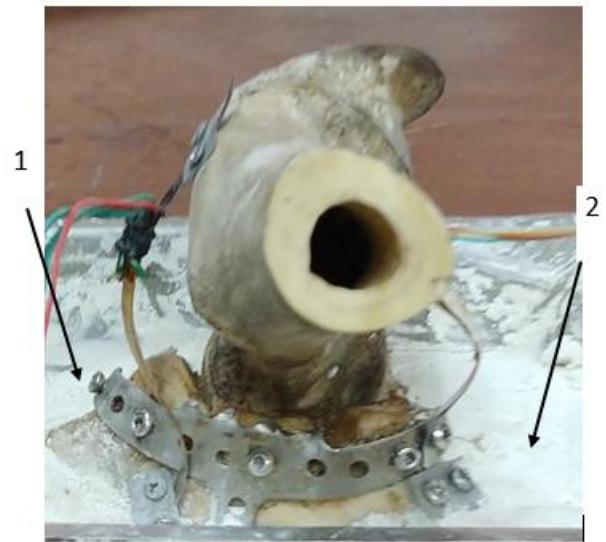


Figure 7. The test sample with a smoothly curved arc-shaped plate and with installed displacement sensors 1 and 2

3. Results and Discussion

Measuring any sample parameter requires the use of measuring transducers. The reliability of the obtained results depends on how optimally the parameters of the measuring transducers are selected and the extent to which their characteristics meet the experimental objectives. A crucial step in preparing for experiments is the calibration of the measuring channels, taking into account the influence of all the measuring systems involved in the process.

For the production of strain gauge displacement transducers, thin elastic steel plate-type springs of varying base lengths and widths are prepared. The dimensions of each strain gauge displacement transducer are individually selected, taking into account the characteristics of the parameters being recorded and their installation location. One of the key requirements for installing the transducers on the test object is that they must operate under elastic loads within the measured range, without imparting additional force to the system. These specially prepared strain gauge displacement transducers, consisting of an elastic flexible steel plate, have a thickness of $\delta = 0.08$ mm and a plate width of a ≤ 10.0 mm.

Strain gauges with varying base lengths and resistances are used in the manufacture of displacement sensors. Depending on the strain gauge's base length and design, the range of measured values can be expanded to suit the experimental setup. 2FKPA-30-200 HV strain gauges with a 30 mm base and 200 ohm resistance were used in the manufacture of displacement sensors (Fig. 8).

Before installing displacement sensors on the test object, they are individually calibrated on a special stand using a measuring system. To calibrate and install the sensors on the

test object, holes are made in the plates along the edges for securing them with screws. We have a special stand for calibrating displacement sensors, which allows for calibration of sensors for both small and large deformations of samples.

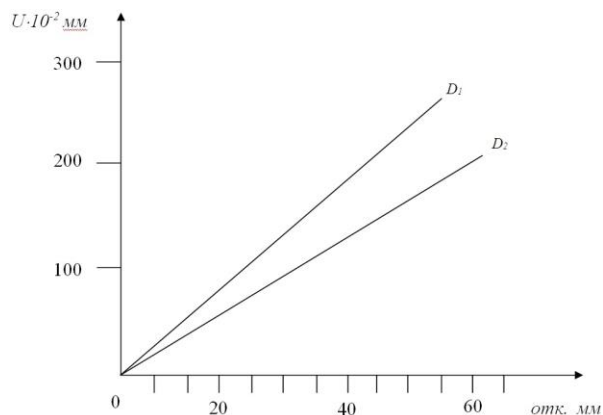


Figure 8. Calibration graphs of displacement sensors: D1 – sensor No. 1; D2 – sensor No. 2

Measuring complex. In order to improve the instrumental data recording system, a new research methodology has been developed using a measuring complex based on computer technology with software for processing experimental results.

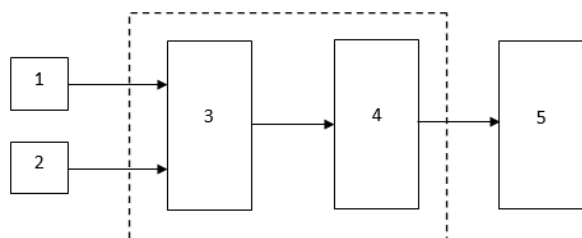


Figure 9. Electronic block diagram of the measuring complex

In general, the measuring system consists of two displacement sensors (1) and (2), an amplifier (3), an analog-to-digital converter (ADC) (4), and a computer (1) with software (Fig. 2). The amplifier (3) and ADC (4) are located in the same housing, indicated by the dotted line.

The operating principle of the measuring system according to this measuring block diagram. When a load is applied to a test specimen with a smoothly curved arc-shaped plate and installed displacement strain gauges, the specimen changes its position in space. The strain gauges attached to the specimen experience compression and change their resistance. This change in resistance generates electrical signals proportional to the load. Signals from the displacement gauges (1) and (2) are fed to the input of the amplifier (3), where they are amplified. The amplified signals are fed to the analog-to-digital converter (4), which converts the analog signals from the strain gauges into digital code for the computer (1). The data processing program calculates the strain of the test specimen and displays this process on the computer monitor.

Figure 3 shows the displacement of the head of the tibia relative to the acetabulum.

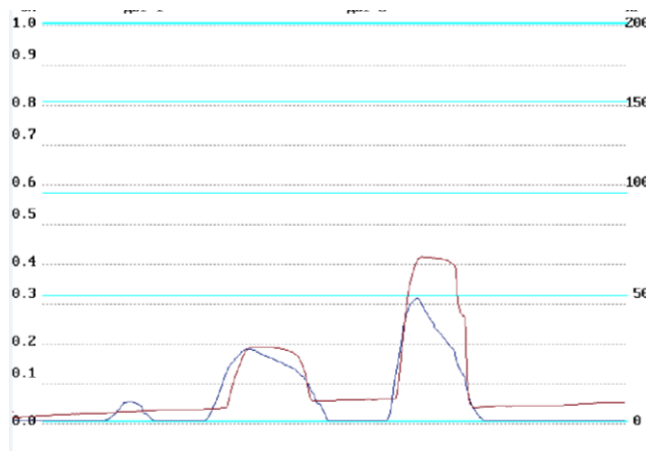


Figure 10. Changes in the displacement of the tibia head relative to the acetabulum

Experimental studies of the device were conducted in the laboratory "Experimental studies of the strength of structures and seismic resistance of structures" of the Institute of Mechanics and Seismic Resistance of Structures of the Academy of Sciences of the Republic of Uzbekistan.

After calibration and preparatory work, the ready-to-use sensors are installed on the test object. The measuring sensors were installed taking into account the changes in the displacement of the elements in two mutually parallel directions.

Tests were conducted with the system repeatedly loaded and unloaded. Movements of bone components near the simulated damaged area where the device was implanted were recorded using displacement sensors.



Figure 11. General view of the installation of the universal testing machine UIM-50

For compression studies, experiments were conducted on a UIM-50 universal testing machine. Figure 1 shows a general view of the setup. Figure 12 shows the test object with a DOSM-0.2-10 dynamometer.

To obtain complete information about bone displacement during the experiment, a device was installed near the damaged area of the acetabulum. The sensors are positioned parallel to

each other and provide information on vertical bone displacement. The average displacement value is taken from the readings from the two sensors.



Figure 12. The test object with the dynamometer DOSM-0.2-10



Figure 13. General view of the electrical measuring complex

The experiments were conducted in the following sequence. After assembly and adjustment of the electrical measuring system, it was connected to the measuring complex. The operability of the measuring instruments and equipment was checked. Then, we proceeded to loading the system under study. A concentrated vertical load was applied to the system through a DOSM-0.2-10 dynamometer. The numerical value of the load was recorded using the KI indicator located inside

the DOSM-0.2-10 dynamometer. By gradually increasing the load on the test object, we recorded the displacement values on each sensor. The numerical readings of the sensors may vary, but the actual displacement values are the same. Thus, a series of experiments was conducted under various compressive loads, and data on the displacement values in the system were obtained.

All obtained records from the experiments were processed and analyzed. After processing the records, we obtained the necessary information about the behavior of the device under study. Based on the obtained experimental values, a graph was constructed showing the change in relative displacement at the simulated damaged area as a function of the compressive load (Figure 14).

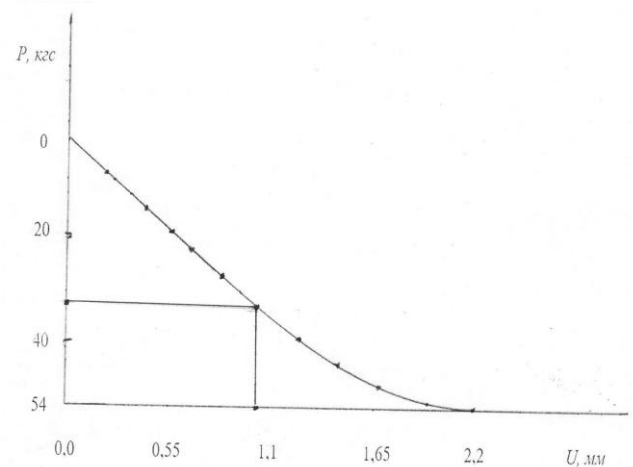


Figure 14. Graph of change in relative displacement depending on compressive load

The presented dependence of the compressive load on the relative displacement of the bone components was obtained by repeatedly axially loading and unloading the system. As can be seen from the graph, the system structure operates elastically under axial compression up to a load of $P = 33.0$ kgf, i.e., without residual deformation. Further increases in load lead to plastic deformations in the bone component system. At a load of $P = 54.0$ kgf, a portion of the tibia contacts the acetabulum. Further increases in load lead to deflection of the device and deformation of the device itself.

4. Conclusions

1. A method has been developed for measuring relative micro-displacements at the installation site of a device for treating acetabular fractures under the action of compressive loads of varying intensity.
2. The maximum numerical values of the load at which the plate operates in elastic mode were determined to be $P = 33.0$ kgf. The maximum total deformation is $U_{mm} = 0.48$ mm, and there is no residual deformation. Further increases in load lead to residual deformation, the value of which increases with increasing applied load.

3. The material used for the device ensures the necessary strength during use.

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