EXPERIMENTAL STUDY

Does an infra pectineal plate alone provide adequate fixation in anterior column posterior hemitransverse acetabular fractures? A comparative biomechanical study

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ABSTRACT

BACKGROUND: The purpose of this study is to compare biomechanical properties of suprapectineal (SP) plate fixation, infrapectineal (IP) plate fixation, and both SP and IP plate fixation in anterior column posterior hemitransverse (ACPHT) fractures of the acetabulum using posterior and anterior column screws.

METHODS: In 21 hard plastic left hemipelvis models, ACPHT fractures of the acetabulum were created, and in three different fixation groups, the methods were compared: Group 1: SP plating using a 3.5 mm reconstruction plate and cortical screw fixation, Group 2: İnfrapectineal plating using 3.5 mm reconstruction plate and cortical screws combined with posterior and anterior column screws, and Group 3: Combined fixation with SP and IP plating using 3.5 mm reconstruction plates and cortical screws. Maximum load to failure (strength) of these three groups was compared between groups.

RESULTS: The mean maximum load of failure for three groups was 2921 N, 2018 N, and 3658 N, respectively. When strength was compared considering the force that causing implant failure, it was determined that the strongest fixation was achieved when SP and IP fixation method were applied together, followed by SP only fixation and IP fixation supported by anterior and posterior column screws, respectively.

CONCLUSION: The combined application of SP and IP fixation provides the most stable fixation of the ACPHT acetabular fractures, and IP fixation does not provide comparable biomechanical stability despite reinforcement with three-column screws placed away from the plate. Although IP fixation supported by anterior and posterior column screws with the limited combined approach is less invasive approach for patients, SP fixation should be included in the surgical treatment method to ensure adequate stability.

Keywords: Acetabulum; anterior column posterior hemi transverse; biomechanics; fracture.

INTRODUCTION

Anterior column posterior hemitransverse (ACPHT) fractures are typical acetabular fractures frequently seen in patients aged >65 years. In ACPHT fractures, the force transmitted from the femoral head into the pelvis causes fractures involving the quadrilateral surface (QLS), the medial wall of the acetabulum. Therefore, this fracture pattern is often associated with comminuted fractures and the central dislocation of the femoral head.[1]

Per published clinical and biomechanical studies, surgical treatment for ACPHT among elderly patients is preferable.[2–4] The surgical method frequently used in the early period

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when the surgical approach was widespread in the treatment of ACPHT fractures was suprapectineal (SP) fixation with long periarticular screws using the classical ilioinguinal approach. Due to the difficulty in achieving anatomical reduction of the QLS with the classical ilioinguinal approach in ACPHT fractures, anterior intrapelvic approaches such as the "modified stoppa" method, in which the QLS can be directly explored, have become popular in recent years. The modified Stoppa approach provides intrapelvic but extraperitoneal access to the infrapectineal (IP) area. Thus, the surgeon can access the medial walls of both the anterior and the posterior columns and can place the plate in the same plane as the displacement.[2,4]

Given that most elderly patients have comorbidities and surgical intervention is associated with a high risk of complications, the surgical approach of choice would be one that is least invasive, has least risk of complications, has the least operating time, and provides sufficient stability. Recent reports suggest that the intrapelvic approach along with a limited ilioinguinal approach is safer and requires less application time; however, studies evaluating the biomechanical properties of this fixation alone are scarce.[3]

This study aimed to compare the biomechanical properties of three methods of fixation: (1) The SP plate or (2) IP plate fixation, along with anterior and posterior column screws, and (3) double plate fixation including both the SP and IP areas. We hypothesized that IP fixation alone is biomechanically insufficient, even if reinforced with periarticular long screws and infra-acetabular corridor screw.

MATERIALS AND METHODS

Specimens, Fracture Models, and Test Mechanism Preparation

Per the power analysis performed for this study, 21 purpose-made polyurethane foam adult left hemipelvis models (Synbone AG, Malans, Switzerland, Model No: 4033) were used. Using the reference points in each hemipelvis model, a standard ACPHT fracture model was created per the Letournel-Judet classification. According to Letournel-Judet classifica-

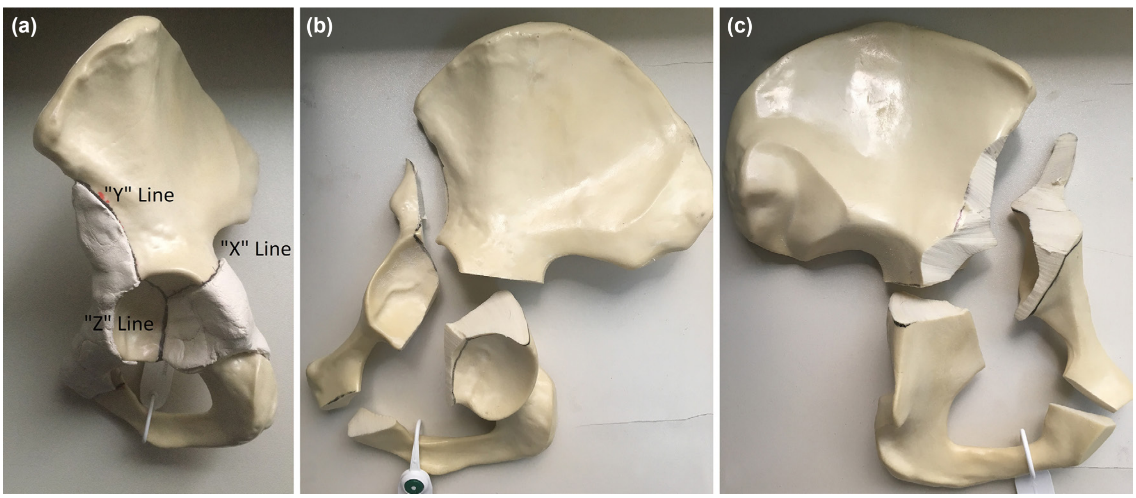

Figure 1. Fracture model created in left hemipelvis model. **(a)** Standardized drawing and definition of fracture lines using sculptural dough. **(b)** Lateral view of the fracture model. **(c)** Medial view of the fracture model.

Figure 2. The experimental setup. **(a)** The position of the experimental setup on the Instron device. **(b)** Metal box setup in which bone models are embedded. **(c)** Femoral stem and head providing load transmission to the acetabular.

tion, considering the coordinate axis system, the fracture line extending from the center of the acetabulum to the iliac wing was defined as the "Y" line, the hemitrasverse fracture line as the "X" line, and the fracture line extending from the inferior of the acetabulum to the anterior was as the "Z" line (Fig. 1).

During the preparation phase, a metal adapter was created to imitate the physiological load to be applied to the acetabulum according to the suggestions of the Mechanical Engineering Department of our university. The metal adapter consisted of a metal box that was adjusted at an angle to allow physiological loading on the hemipelvis models, allowing squeezing of the box placed in it and acting as a chamber. The same metal box setup was used in each experiment (Fig. 2). All hemipelvis models were fixed inside standardized metal boxes separately using dental modeling stones (Denstone 3, Ankara, Turkey) to prevent disruptions in measurements that would occur because of displacement in the coronal and sagittal planes during loading. Load transfer was made to the acetabulum through the femoral stem using a 54 mm bipolar head (Fig. 2). Both the metal adapter and the femoral stem were adapted to the biomechanical measuring device using a 20×1.5 mm bolt. The suitability of the device for the test was confirmed by evaluating the images obtained from the preliminary experiments.

Study Groups and Instrumentation

Three homogeneous study groups were created based on the method used to fix the ACPHT acetabular fracture in the hemipelvis model. Each group consists of seven pelvic models. Titanium conventional reconstruction plates (3.5 mm, ten holes) and titanium cortical screws were used in all groups. After all the plates were anatomically contoured, the proximal and distal ends of the both SP and IP plates were fixed with two cortical screws. After that two periarticular long cortical screws (90 mm and 110 mm) to the posterior column and 1 screw (80 mm) through the infra-acetabular corridor into the anterior column were placed from the SP area through plate in SP group and away from the plate in IP group. The fracture line proximal to the anterior column was fixed to the iliac wing with one cortical screw. The number of screws and their configurations were decided based on previous biomechanical studies.[5,6]

In Group 1, pelvic reconstruction plates were fixed on the SP area. Anterior and posterior column screws were placed through the plate (Cytronics, Bursa, Turkey) (Fig. 3).

In Group 2, pelvic reconstruction plates were fixed on the IP area. Anterior and posterior column screws were placed away from the plate from SP area (Cytronics, Bursa, Turkey) (Fig. 3).

In Group 3, fixation was achieved using double plating with pelvic reconstruction plates located on the SP and IP areas.

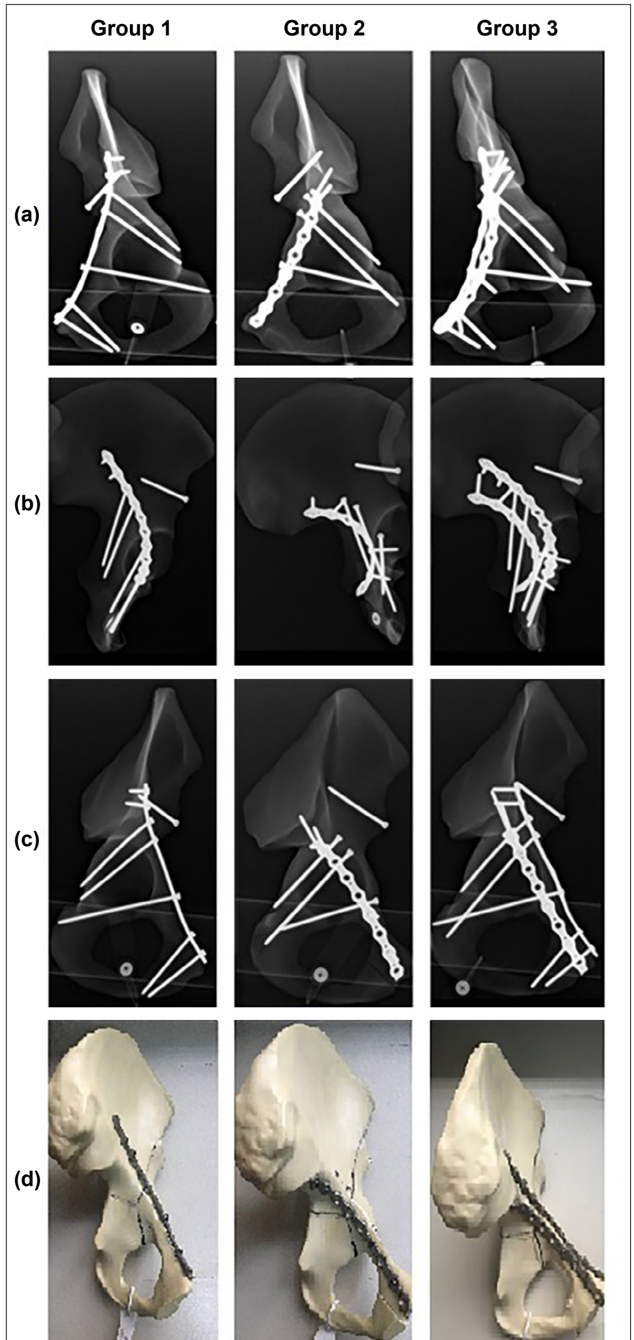

Figure 3. X-ray images and post-fixation view of the study groups. **(a)** Anterior-posterior view. **(b)** İliac oblique view. **(c)** Obturator oblique view. **(d)** Post-fixation view.

Anterior and posterior column screws were placed through the SP plate (Cytronics, Bursa, Turkey) (Fig. 3).

Biomechanical Test Configuration and Mechanical Measurements

Three different fixation methods were compared biomechanically under vertical loading using an automated material testing machine (Instron Model No: 8874; Instron Corp, Canton, MA). Hemipelvis models were fixed before each experiment ensuring proper configuration of the Instron device. During this fixation, all hemipelvis models were positioned as standard to ensure that the load is transmitted to the acetabulum in the same direction as the joint reaction force (at a 13° angle with the sagittal plane).[7] The force-applying bipolar head, acetabulum, and the load unit that measured the force were on the same vertical axis on both anterior-posterior and lateral planes. Before each experiment, a 100-N compression force was applied, and compression was performed between the hemipelvis model connected to the measuring cell and the femoral stem. The indicator detecting the change in distance on the test machine at 50-N preload was then reset.

The biomechanical compression test was carried out within a measuring range of 5 mm/min with axial loading continued until the development of a failure. The implant and system structures were deemed insufficient when a prolonged decrease was observed after the peak point on the force-displacement graph; the test was then terminated.

In the static loading model, strength was evaluated during mechanical measurement; strength was the magnitude of force applied until insufficiency developed. During the biomechanical compression test, loosening of the screw head or the protrusion of grooves of one or several screws, separation of the plate from the fixation points, or >3 mm displacement in the fracture line were considered as insufficiencies. In the experimental setup, both compression forces and bending forces affected the implants. Anatomically, force was applied to and measurements were taken from the rotation center of the hip joint.

Statistical Analysis

The Levene test was used to determine homogeneous distribution among groups. The normality of the distribution among the groups was determined using the Shapiro-Wilk test. Differences among groups in the magnitude of force causing implant failure were determined using the post hoc Tukey test of the variance analysis test before applying the Levene test for each parameter. Data were analyzed using SPSS (Statistical Package for the Social Sciences, version 11.5, SPSS Inc, Chicago, IL, USA) and $p<0.05$ were considered significant.

RESULTS

Group Averages

The mean maximum load to failure and the most common types of implant failures were recorded for each group.

Group 1

For Group 1, the mean maximum load to failure was 2922±609 N (2350–3872 N). The most common implant failure was a separation in the X fracture line extending to the iliac wing and fracture in the iliac wing (3/7). Other implant failures in this group included hemitransverse fracture line X and separation in line Y (2/7), separation in line Y (1/7), and fracture line Z extending anteriorly to the inferior acetabulum (1/7) (Fig. 4).

Group 2

The mean maximum load to failure in Group 2 was 2019±362 N (1323–2394 N). The most common implant failure was a separation in the X line and in all directions on the QLS (3/7). Other implant failures in this group included separation in the Z line and all directions in the QLS (2/7) and in the X line (2/7) (Fig. 4).

Group 3

The mean maximum load to failure in this group was 3658±456 N (2956 N–4349 N). The most common implant failure was a separation in the “X” line (4/7). Other implant failures included a separation in the Y line (1/7), separations in the X and Z lines (1/7), and separations in the X, Y, and Z lines and a separation in the QLS (1/7) (Fig. 4).

Mechanical Results

The inter- and intra-group distributions of the maximum load to failure were homogeneous. On comparing implant failures across groups, the mean strength (maximum load to failure) was the highest in Group 3, followed by Group 1 and Group 2 (Fig. 5 and Table 1). Assessing the model strength of each group showed force-frequency curve shifts significantly to the right, with the highest shift in the group with the least strength and the shift diminishing in groups with more

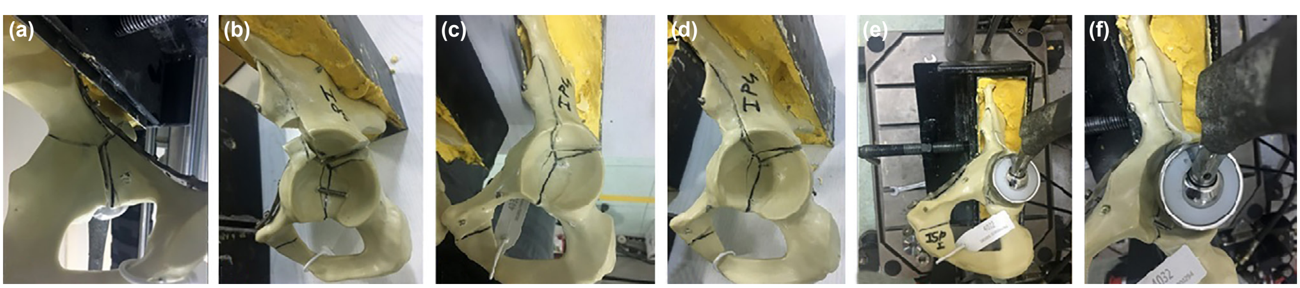

Figure 4. Implant failures in each group. **(a)** Implant failure in the first group: Medial view, separation in Z line. **(b)** Implant failure in the first group: Lateral view, fracture in X line, and separation in Y line. **(c)** Implant failure in the second group: Separation in the line leading to the iliac wing. **(d)** Implant failure in the second group: Separation in the hemitransverse fracture line. **(e)** Implant failure in the third group: Separation in the X line to the iliac wing. **(f)** Implant failure in the third group: Failure development with separation in X and Y line.

Table 1. The statistical comparison of the group strengths

Strength	Group 1	Group 2	Group 3
Group 1	–	<0.01	–
Group 2	–	–	<0.01
Group 3	<0.05	–	–

P<0.05.

strength (highest in Group 2 and lowest in Group 3) (Fig. 6). This shift to the right indicates that Group 3 models had greater strength than those in the other groups. Force-deformation graphics of biomechanical experiments in all groups are shown in Figure 7.

DISCUSSION

The incidence of acetabular fractures has increased 2.4 times over the past 25 years and increase in incidence of acetabular fractures is the highest among the geriatrics. In the elderly population, ACPHT fractures often develop in which the integrity of the QLS of the acetabulum is disrupted and protrusion of the femoral head into the pelvis is observed.[8] Anatomical reduction is the main goal in the treatment of these fractures involving the QLS to obtain a functional hip joint. On the other hand, a mechanically adequate fixation method should be used to maintain internal fixation until the fracture heals.[2] There is a debate in the literature regarding the internal fixation method that should be used in the surgical treatment of ACPHT fractures. Although many studies have been conducted evaluating the biomechanical properties of different fixation methods,[1–3,6] our study is the first study evaluating the biomechanical properties of SP fixation, IP fixation, and double plate fixation using conventional pelvic reconstruction plates. The present biomechanical study shows that the IP plate fixation is biomechanically insufficient, although it is supported by anterior and posterior column screws placed freely from the SP area.

To obtain accurate test results during the creation of loading models, it is important to mimic the natural biomechanical properties of the hip joint. Most past biomechanical studies have used double-leg loading models, wherein the load was transferred over the lumbar vertebra to the pelvis, or single-

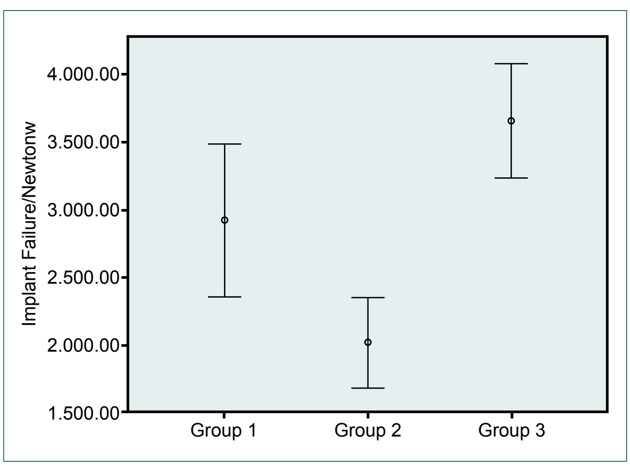

Figure 5. Average force causing implant failure between groups.

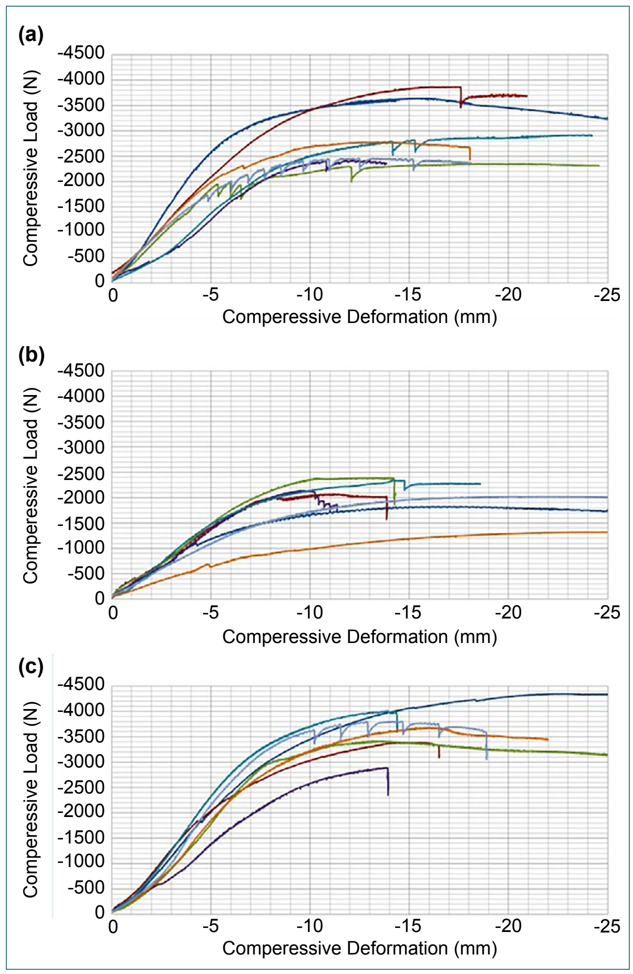

Figure 7. (a-c) Force-deformation graphics of biomechanical experiments.

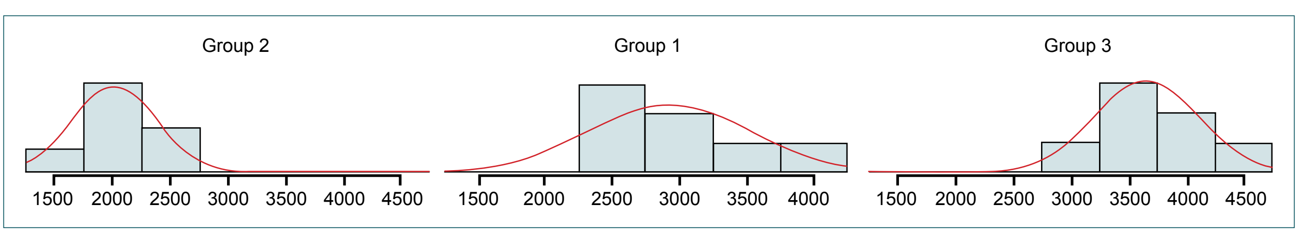

Figure 6. Force ranges and frequency curve that cause implant failure within each group.

leg loading models, wherein the load was transferred to the acetabulum directly.[9–11] Lateral compression loading models, which are frequently used to evaluate the biomechanical strength of the fixation of QLS,[3,4] do not simulate physiological biomechanical conditions. Hence, we devised a test setup that allows evaluation of the fixation method under normal physiological single-leg loading.

The previous studies have used dynamic loading or static loading models or models that used both for biomechanical evaluations.[3,9,12–14] Similar to Spitler et al.,[14] we applied static loading using the Instron device. To achieve optimal results, biomechanical devices that mimic the normal walking phases by allowing movement at a full range of motion are needed for future studies.

In biomechanical studies in the literature, high-resolution cameras and specialized transmitters can be used and data are analyzed with unique software.[4,6,10] We obtained measurements by applying the load on a single plane and did not use any three-dimensional modeling. In addition, we obtained the images with a high-resolution digital camera during and after the testing of each material and determined the mechanism of failure. On the other hand, similar to other biomechanical studies, we applied the force entirely in the cranio-caudal direction and aimed to build the study model inexpensively so the tests can be repeated easily without simulating any muscle or ligament support.

Composite bone models are often preferred in the literature given the difficulty of obtaining fresh cadavers and to prevent anatomic differences between samples.[1,3,9,10,15] The recent composite pelvis models, (4th generation) are characteristically very similar to human bone tissue.[4,6] Although using these models positively improves biomechanical analysis, the 4th generation composite models are considerably more expensive other composite models. In this study, we used anatomically compatible standard hemipelvis models that have been previously used in biomechanical studies.

A review of the existing literature shows that the strongest fixation method for ACPHT fractures of the acetabulum invariably involves SP plate-screw fixation.[1–3,6] In addition, per past studies, a stable QLS can be obtained with perpendicularly placed long periarticular screws regardless of the fixation method.[6,16] Thus, in contrast with other studies, we utilized three-column screws through or away from the plate for all groups. Studies have shown that SP fixation provides the strongest fixation when strengthened with IP fixation;[3] however, in these studies, IP plating alone was not evaluated with the addition of the column screws. We found that the strongest fixation was obtained in Group 3, in which both SP and IP fixations were applied together in accordance with the literature. The type of IP plate used and method of application vary in the literature.[1,2,10] Pelvic reconstruction plates and distinct QLS plates are used to create a buttress effect on the QLS. In addition, these plates can be applied vertically or horizontally to achieve the strongest fixation. However, studies have shown that distinct buttress plates applied to the QLS do not provide additional biomechanical support.[1,2] In this study, we achieved IP fixation using a 3.5 mm pelvic reconstruction plate applied horizontally. The second strongest fixation was obtained in Group 1, wherein SP plate and column screw fixation were applied. In this group, the region where most insufficiencies developed was the fracture line extending to the iliac wing, indicating this as the weakest point of the fixation is this region. Therefore, we suggest that strengthening of this area is necessary for SP plating. Among Group 2 models, which had the least strength, the separation on the QLS was more frequent than in the other groups. This shows that periarticular long screw fixation applied perpendicularly to the QLS provides better durability when applied through the plate. However, despite reinforcement with IP fixation, we found that IP fixation alone was biomechanically inadequate.

This study has few limitations. First, only the static loading model was used. Furthermore, during the test, displacement in fracture lines could have been observed immediately using special transmitters instead of high-resolution cameras. Composite pelvis models do not simulate biomechanical properties of the natural bone. Using the cadaveric pelvis or 4th generation biomechanical pelvis could have yielded a better simulation of physiological conditions.

Conclusion

Although the data obtained from this study cannot be compared with clinical results, the preservation of the reduction obtained after fixation depends on the strength of the fixation method applied. Although IP plate screw fixation does not provide comparable biomechanical stability despite reinforcement with three-column screws placed away from the plate when compared to SP or double plate fixation. According to this study, the best fixation for ACPHT fractures is double plating with column screws through the SP plate.

Ethics Committee Approval: This study was approved by the Başkent University Ethics Committee (Date: 17.07.2019, Decision No: 94603339-604.01.02/33115).

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Authorship Contributions: Concept: E.K.Ş.; Design: B.H., E.K.Ş.; Supervision: H.D.; Resource: B.H.; Materials: A.M., B.C.B.; Data: B.C.B.; Analysis: E.K.Ş., A.M.; Literature search: E.K.Ş., A.M.; Writing: E.K.Ş., B.H.; Critical revision: H.D.

Conflict of Interest: None declared.

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DENEYSEL ÇALIŞMA - *ÖZ*

Asetabulumun anterior kolon posterior hemitransvers kırıklarında infrapektineal plak tek başına yeterli tespit sağlar mı? Karşılaştırmalı biyomekanik çalışma

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AMAÇ: Bu çalışmanın amacı, asetabulumun anterior kolon posterior hemitransvers (AKPHT) kırık tipinin oluşturulduğu hemipelvis modelinde; arka ve ön kolon vidaları ile desteklenmiş infrapektineal tespit yöntemi, suprapektineal tespit yöntemi ve suprapektineal ile birlikte infrapektineal çift plak tespit yöntemlerinin biyomekanik olarak karşılaştırılmasıdır.
GEREÇ VE YÖNTEM: Çalışmada poliüretan köpükten özel olarak üretilmiş 21 adet sol hemipelvis modelleri üç ayrı gruba ayrıldıktan sonra Letournel-Judet sınıflandırmasına göre anterior kolon posterior hemitransvers asetabulum kırığı oluşturuldu. Grup 1; suprapektineal yerleşimli 3.5 mm rekonstrüksiyon plak/vida tespiti ve plak üzerinden iki adet arka kolon ve bir adet ön kolon vidası uygulaması, Grup 2; infrapektineal yerleşimli 3.5 mm rekonstrüksiyon plak/vida tespiti ve suprapektineal alandan serbest olarak uygulanan iki arka kolon ve bir ön kolon vidası uygulaması, Grup 3; suprapektineal ve infrapektineal yerleşimli 3.5 mm rekonstrüksiyon plak/vida tespiti ve suprapektineal plak üzerinden iki adet arka kolon ve bir adet ön kolon vidası uygulaması. Çalışma gruplarında uygulanan farklı tespit yöntemleri, biyomekanik olarak otomatik materyal test makinesi kullanılarak vertikal yüklenme altında dayanıklılık bakımından test edildi ve elde edilen sonuçlar istatistiksel olarak karşılaştırıldı.
BULGULAR: Tüm gruplarda, sırası ile implant yetmezliği gelişmesine neden olan ortalama maksimum kuvvet miktarı sırasıyla 2921 N, 2018 N ve 3658 N olarak belirlendi. İmplant yetmezliğine neden olan kuvvet göz önünde bulundurularak dayanıklılık karşılaştırıldığında, en dayanıklı tespitin suprapektineal ve infrapektineal tespit yönteminin birlikte uygulandığında sağlandığı, bunu sırasıyla suprapektineal tespit ve ön ve arka kolon vidaları ile destelenmiş infrapektineal tespit takip ettiği belirlendi.
TARTIŞMA: Bu çalışmada, asetabulumun AKPHT kırıklarında, suprapektineal ve infrapektineal tespit yönteminin birlikte uygulanmasının en stabil tespiti sağladığını, dayanıklılık açısından bunu suprapektineal tespitin takip ettiğini ve arka ve ön kolon vida uygulaması ile desteklenmiş infrapektineal tespit'in tek başına yetersiz olduğunu belirledik. Asetabulumun anterior kolon posterior hemitransvers kırıklarında limitli kombine yaklaşım ile uygulanan anterior ve posterior kolon vidaları ile desteklenmiş infrapektineal tespit hastalar için daha az invaziv olsa da yeterli stabiliteyi sağlamak için suprapektineal tespit, mutlaka cerrahi tedavi yöntemine dahil edilmelidir.
Anahtar sözcükler: Anterior kolon posterior hemitransvers; asetabulum; biyomekanik; kırık.

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