Biomechanical Comparison of Fixation Methods for Posterior Wall Fractures of the Acetabulum: Conventional Reconstruction Plate vs. Spring Plate vs. Variable Angle Locking Compression Plate

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Biomechanical Comparison of Fixation Methods for Posterior Wall Fractures of the Acetabulum: Conventional Reconstruction Plate vs. Spring Plate vs. Variable Angle Locking Compression Plate

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감사의 글

박사학위를 시작한 이후 예상치 못했던 COVID-19 팬데믹 기간을 거치며 긴 시간이 흘렀습니다. 이 여정을 완주할 수 있었던 것은 많은 분들의 도움과 격려 덕분입니다. 이 자리를 빌려 그분들께 진심으로 감사의 말씀을 드리고자 합니다.

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아울러, 연구에 귀중한 조언을 아낌없이 해 주신 고려대학교 오종건 교수님, 조재우 교수님, 그리고 아주대학교 조원태 교수님께도 깊이 감사드립니다. 그리고 3D 프린팅 제작에 도움을 주신 이천의 교수님께도 감사의 말씀을 전합니다. 또한, 어려운 생역학 사체 연구를 함께 진행하며 큰 도움을 주신 곽지웅 선생님과 이상호 선생님께도 진심으로 감사를 드립니다. 두 분의 협력과 헌신 덕분에 연구를 잘 마무리 할 수 있었습니다.

마지막으로, 묵묵히 저를 응원하며 변함없는 사랑과 지지를 보내준 아내에게 깊은 감사를 전합니다. 당신의 믿음과 헌신 덕분에 어려운 순간에도 끝까지 노력할 수 있었습니다. 또한, 언제나 밝은 미소로 저를 응원해 준 사랑스러운 선유와 지유, 그리고 아낌없는 사랑과 헌신으로 저를 키워 주신 아버지와 어머니, 장모님께 이 학위를 바칩니다. 가족 모두의 희생과 사랑이 있었기에 여기까지 올 수 있었습니다. 앞으로도 이 감사한 마음을 잊지 않고, 제가 받은 사랑과 가르침을 바탕으로 진실되고 성실하게 살아가겠습니다.

2024 년 12 월

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ABSTRACT

Biomechanical Comparison of Fixation Methods for Posterior Wall Fractures of the Acetabulum: Conventional Reconstruction Plate vs. Spring Plate vs. Variable Angle Locking Compression Plate

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Acetabular fractures, though infrequent, present considerable challenges in treatment due to their association with high-energy trauma and poor prognoses. Posterior wall fractures, the most common type among them, typically have a more favorable prognosis compared to other types. Anatomical reduction and stable fixation of the posterior wall are crucial for optimal treatment outcomes. This study aimed to biomechanically compare three commonly used fixation methods for posterior wall fractures of the acetabulum: conventional reconstruction plate, spring plate, and 2.7mm variable angle locking compression plate (VA-LCP). The study utilized 6 fresh-frozen cadavers, yielding 12 hemipelvises free from prior trauma or surgery. Three fixation methods were compared using a simple acetabulum posterior wall fracture model. Fixation was performed by an orthopedic specialist, with prebending of plates to minimize errors. Hemipelvises were subjected to quasi-static and cyclic loading tests, measuring fracture gap, stiffness, and displacement under load. It showed no significant differences in fracture gap among the three fixation methods under cyclic loading conditions simulating walking. However, the conventional reconstruction plate exhibited greater stiffness compared to the spring and variable angle plates. Fatigue analysis revealed no significant differences among the plates, indicating similar stability throughout cyclic loading. Despite differences in stiffness, all three fixation methods demonstrated adequate stability under loading conditions. While the conventional reconstruction plate demonstrated superior stiffness, all three fixation methods provided sufficient stability under cyclic loading conditions similar to walking. This suggests that postoperative limitations are unlikely with any of the three methods, provided excessive activities are avoided. Furthermore, the variable angle plate -like the spring plate- offers appropriate stability for fragment-specific fixation, supporting its use in surgical applications. These findings contribute to understanding the biomechanical performance of different fixation methods for acetabular fractures, facilitating improved surgical outcomes in challenging cases.

Keywords: biomechanics; acetabulum; posterior wall fracture; variable angle plate

1. Introduction

Acetabular fractures are relatively uncommon but present significant treatment challenges, primarily due to their association with high-energy trauma, often resulting in poor prognoses [1,2]. Among the various classifications, posterior wall fractures are the most prevalent and are generally associated with a relatively simpler treatment approach and better outcomes [3,4]. These fractures can be managed either non-surgically or surgically, depending on the stability and congruence of the fracture. Non-surgical treatment is considered for stable, congruent posterior wall fractures [5], whereas surgical intervention is recommended when fractures lead to hip joint instability or incongruity [6]. According to Moed et al., posterior wall fragments that comprise more than 50% of the hip joint surface on a CT scan are deemed unstable [7,8]. For borderline cases, examination under anesthesia (EUA) is utilized to assess the stability and to determine the necessity for surgery [9]. The standard surgical approach typically involves open reduction and internal fixation (ORIF), with total hip arthroplasty being an option for severely comminuted fractures in elderly patients [2,10]. Achieving an anatomical reduction and stable fixation of the posterior wall is crucial for successful outcomes [10-12].

Various techniques for fixing posterior wall fractures have been developed, including the use of plates, lag screws, and spring plates [13-17]. Locking compression plates (LCPs) are gaining favor in orthopedic trauma treatments due to their enhanced stability and the presumed benefits in osteopenic bone. These plates reduce the need for lag screws, thus mitigating the risk of intra-articular penetration [18-22]. However, they may pose challenges in managing small peripheral or comminuted fracture fragments due to potential joint penetration post-fixation [23].

Spring plates have proven effective in managing marginal fractures of the posterior wall, as they provide adequate stability without necessitating extensive dissection like larger reconstruction plates [24]. Although spring plates alone do not increase the stiffness of the fixation, they do improve the ultimate yield strength, making them a viable option for marginal and/or comminuted fragments that are unsuitable for lag screw fixation [25].

For superior dome or comminuted posterior wall fractures, the fragment-specific fixation technique using 2.7 mm VA LCP plates represents a promising alternative. This method provides the stable fixation of small fracture fragments, eliminating the need for an overlapping reconstruction plate. Yet, it carries a potential risk of screw joint penetration in peripheral fractures; further biomechanical evaluation of this technique is needed [26].

Recent clinical reports have underscored the efficacy of the 2.7 mm VA LCP for fragment-specific fixation. Research by Cho et al. highlights the advantages of the Variation angle LCP plate in multifragmentary fractures, such as improved positioning of each fragment, reduced soft tissue damage, and enhanced fixation of challenging areas, including the superior dome [26]. Nonetheless, more biomechanical studies are required to fully understand the mechanics of fracture fixation. Clinical trials are crucial, but laboratory tests, including comparative studies using saw bone models and cadaver studies for biocompatibility, also play an essential role in this domain [27-30].

This study aims to perform a mechanical analysis of different fixation plates using a posterior wall fracture model from a cadaveric hemipelvis, with a particular focus on evaluating the stability of the 2.7mm VA-LCP plate, which has been the subject of less clinical research compared to other plates.

2. Materials and Methods

2.1. Cadaveric Specimen Preparation

The study utilized 6 fresh frozen cadavers, yielding 12 hemipelvises, free from trauma, surgery, or metabolic bone diseases. The cadavers, averaging 62.5 years of age (ranging from 53 to 78), consisted of 5 males and 1 female. Stored at -20 °C, the cadavers were thawed at room temperature 24 hours prior to the experiment. After removing surrounding muscles and soft tissues from the pelvis, the bones were cleaned using acetone. The cadavers used were ethically sourced, each donated with informed consent from tertiary care hospitals, in strict accordance with national legal and ethical standards.

2.2. Fixation Methods

For the posterior fracture wall model, three fixation methods were compared. The first method involves fixation using a reconstruction plate with 3.5 mm cortical screws [22]. The second method uses two spring plates. We cut 1/3 of a semitubular plate and took a four-hole one-third tubular plate. First, we cut off the tip through a hole and bent the newly created prongs downwards to create small hooks, fixing it with 3.5 mm cortical screws [24,31]. The third method employs fixation using two 2.7 mm VA LCPs and 2.7 mm locking screws (Figure 1, 2, and 3) [26]. The plates used are as follows: titanium 3.5 mm LCP Reconstruction Plate, DePuy Synthes, Base, Switzerland; titanium 3.5 mm 1/3 Tubular Plate, DePuy Synthes, Base, Switzerland; and Titanium 2.7 mm VA-LCP Cloverleaf fusion plate, DePuy Synthes, Base, Switzerland. Four hemipelves were used for each type of plate.

2.3. Fracture Model Creation

The fracture model employed was a simple acetabulum posterior wall fracture, not considering marginal impaction (AO/OTA classification 62-A1.1) [32]. According to Cho et al. (who investigated the mapping of acetabular posterior wall fractures using three-dimensional virtual reconstruction software: Mimics Medical 21.0 version software, Materialise, Leuven, Belgium and 3-matic Medical 13.0 version software, Materialise, Leuven, Belgium), when viewing the acetabular intraarticular portion as a two-dimensional circle, setting the transverse ligament at 0 degrees, and then considering the acetabular posterior area at a positive angle, the fracture angle 90 degrees included angles from 6.2 to 96.3 degrees. The ratio of the fracture angle 90 degrees and the fragment including the acetabulum rim to the longest part of the acetabulum outer cortex, termed as the 'fracture span', is described. (Figure 4) The shape with a fracture span of 0.65 is reported to be the most common type of posterior wall fracture [33]. Based on this study, we created our posterior wall fracture model. We marked the fracture line on the acetabulum with a pen and created the most common type of posterior wall fracture model using a linear saw.

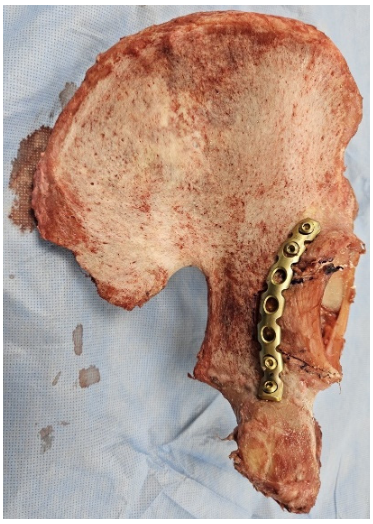

Figure 1. Experimental gross photo of cadaveric posterior fracture wall model fixed with reconstruction plate.

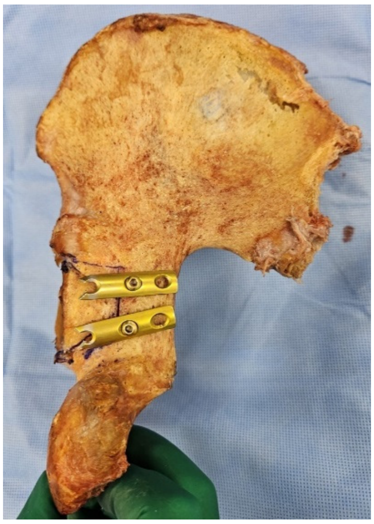

Figure 2. Experimental gross photo of cadaveric posterior fracture wall model fixed with two spring plates.

Figure 3. Experimental gross photo of cadaveric posterior fracture wall model fixed with two variable angle plates.

Figure 4. Posterior wall fracture model of study. We set up the transverse ligament as 0 degrees (for use as a reference point (red line)) and then considered the acetabular posterior area at a positive angle. We made a fracture model using a linear saw by setting the point corresponding to 90 degrees as the most common area for posterior wall fractures (blue line).

Fixation was performed using reduction forceps and pointed ball tip pushers to maintain reduction, keeping the fracture gap within 2 mm. All fixation methods were conducted by an orthopedic specialist. Three-dimensional-printed anatomical models for planning and surgery simulation, patient-specific instruments (PSI), generation of prostheses with 3D-additive manufacturing, and custom 3D-printed prostheses were used. Prebending for each hemipelvis was performed using 3D modeling to minimize errors related to the inherent fixation strength of the plate. Also, proper bending is important to provide sufficient stability [34,35]. The prebending of the reconstruction plate and LCP VA plate, respectively, produced 3D-printed model and was also performed by the same specialist to reduce bias. (Figure 5) We used a 3D printer (Sindoh A1 SD, Sindoh Co., Ltd, Seoul, South Korea, and S-Plastic Model 2.0, Graphy, Seoul, South Korea) as materials.

For representing 3D bone models, Mimics Medical 21.0 version software, Materialise, Leuven, Belgium and 3-matic Medical 13.0 version software, Materialise, Leuven, Belgium were used.

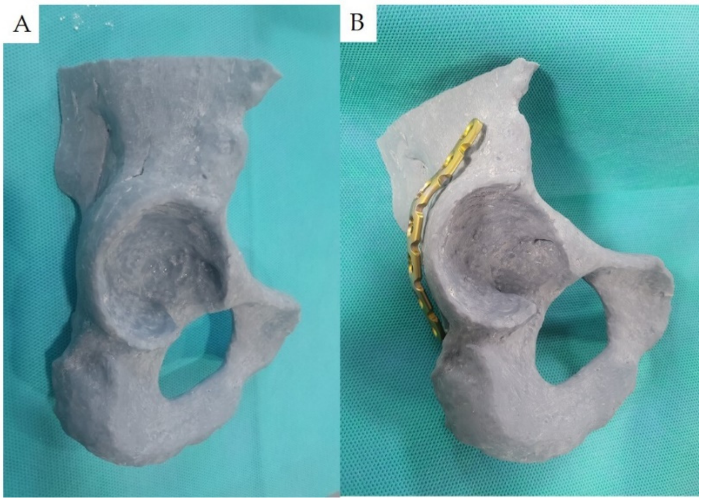

Figure 5. A Three-dimensional printed anatomical models for planning and surgery simulation. B Prebending of plate for each hemipelvis was performed to minimize errors related to the inherent fixation and to provide stability

2.4. Biomechanical Testing Protocols

The posterior wall model was attached to a specially made jig, in which the hemipelvis fit. The Jig was designed to apply loading in a direction perpendicular to the plane connecting the iliac spine and the symphysis pubis, reflecting the direction of maximum loading during rehabilitation and walking. For cycle testing, MultiTest 2.5-I, ILC 2500 N (load cell), Mecmesin Ltd, Horsham, UK was used. For load failure testing, OmniTest 10, ILC 10 KN (load cell), Mecmesin Ltd, UK was used. The jig used in the experiments had a 40 mm metal head for applying loading to the acetabulum; the hemipelvis was fixed using 10 bolts drilled through the jig to minimize error due to size and rotational variables [36].

For each fixation method, the hemipelvis was fixed to the specific jig, and the jig's metal head was aligned perpendicularly to the fracture site. Both quasi-static loading and cyclic loading tests were conducted, with quasi-static loading measuring the force until mechanical failure - defined as the point where the compression force and the plate's buttress force diverged from linearity. (Figure 6) The Vector pro MT program (Mecmesin Ltd, UK) software was used for force measurements [37].

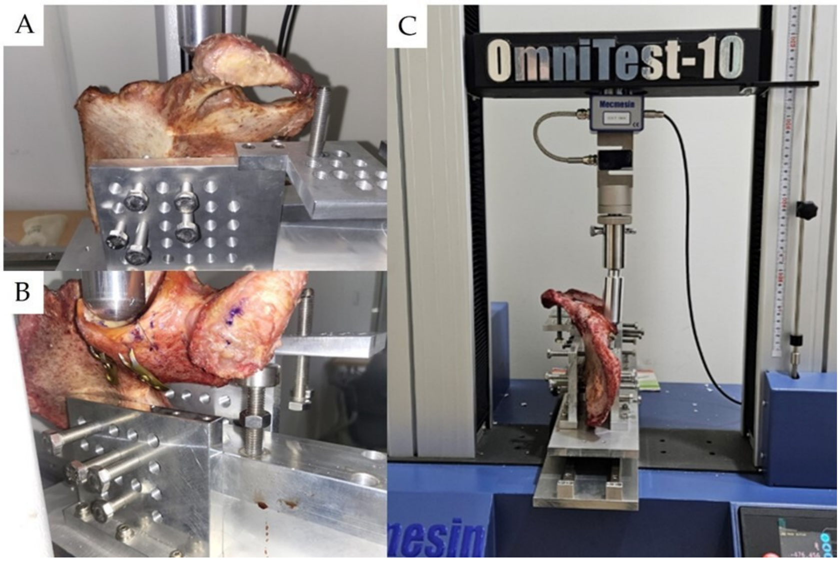

Figure 6. Scheme of experiment. (A) The jig was manually adjusted using metal bolts and was fixed to the posterior wall model. (B) The jig was manually adjusted using metal bolts and was fixed to the posterior wall model. (C) Both quasi-static loading and cyclic loading tests were conducted, with quasi-static loading measuring the force until mechanical failure. The cyclic test was set biomechanically based on a 70 kg subject, with the maximum loading during walking being set at 1400 N. The preload was set at 1000 N for 1000 cycles, followed by 1400 N for another 1000 cycles at a frequency of 1Hz.

The cyclic test was set biomechanically based on a 70 kg subject, with the maximum loading during walking being set at 1400 N (2.0-3.5 times body weight) [38,39]. The preload was set at 1000 N for 1000 cycles, followed by 1400 N for another 1000 cycles at a frequency of 1Hz. The EmperorTM program (Mecmesin Ltd, UK) was used for measuring force, stiffness, and displacement during the test. The experiment was concluded when displacement exceeded 2 mm.

Furthermore, this study also conducted a fatigue study for each type of plate during cyclic testing. Fatigue is defined as the difference in the interfragment gap observed after 100 preloads in a 10,000-cycle test, namely the difference between the gap at 1500N and the gap at free load, which is set as the starting point value. The difference in the interfragment gap at the end of 10,000 cycles is set as the endpoint value. The fatigue of the plate is defined as the difference between the gap at the endpoint and the starting point.

To minimize bias, subjects with the highest and lowest displacements were excluded from the statistical analysis. In our study, subjects with the highest and lowest displacements were excluded from the statistical analysis to minimize bias. This aligns with standard biomechanics practices, as extreme values can disproportionately influence results. Barnett and Lewis in 'Outliers in Statistical Data' recommend excluding such data points if they distort outcomes [40]. Our methodology follows these principles to accurately represent biomechanical effects.

2.5. Statistical Analysis

Data are presented as mean ± standard deviation. Displacement data from different experimental groups were analyzed using one-way ANOVA, with a 95% confidence level indicating significant differences. R statistical programming language (R Foundation for Statistical Computing, Vienna, Austria) version 4.3.1 for Windows, was utilized for statistical analysis.

3. Results

3.1. Fracture Gap Analysis

Table 1 displays the mean fracture gap observed in experiments conducted with a 1500N force according to the cyclic test protocol. ANOVA analysis revealed no statistically significant differences when comparing the conventional reconstruction plate with the spring plate, the spring plate with the variable angle plate, or when all three were compared together. This suggests that, in a cyclic test scenario, where plates are subjected to a force of 1500 N over 10,000 cycles, there is no discernible difference in the ability of the plates to withstand the load. (Figure 7)

3.2. Stiffness Evaluation

Table 2, however, showed that the conventional reconstruction plate had statistically significant results compared to the other two plates. When each plate was analyzed one-on-one, the conventional reconstruction plate demonstrated significant results against both the spring plate and the variable angle plate, indicating that the stiffness of the conventional reconstruction plate is stronger than the other two. However, no significant difference in stiffness was found between the variable angle plate and the spring plate (Figure 8, 9).

3.3. Fatigue Performance

Statistical analysis of the fatigue values for each plate showed no significant differences among the three types of plates (Figure 10). This indicates that there were no discernible differences in the material properties and design of the plates when subjected to repeated loads of 1500 N over 10,000 cycles. Fatigue results showed no significant differences, and it was decided to proceed accordingly. There was a cyclic test failure in one model using 2.7 mm LCP VA plate out of a total of 12 hemipelvis. An obvious porosity was observed in the evaluation of the surgeon who conducted the experiment. We assumed this to be the cause of the cyclic test failure.

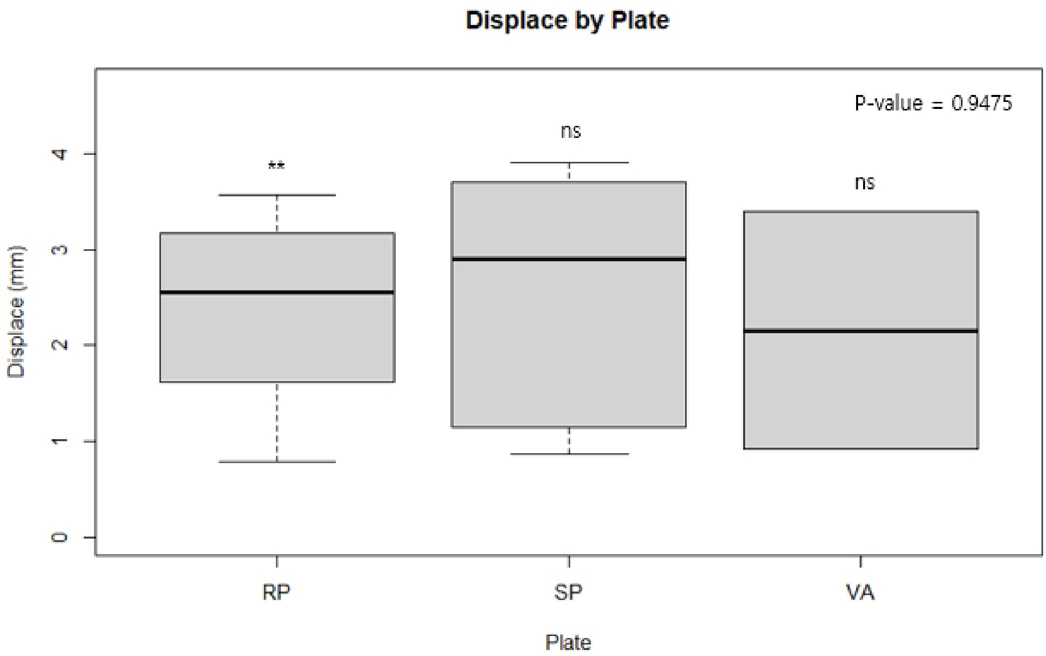

Figure 7. The mean fracture gap of each plate in cyclic test protocol. plates are subjected to a force of 1500 N over 10,000 cycles and the experiment was concluded when displacement exceeded 2 mm. ANOVA analysis revealed no statistically significant differences when comparing the conventional reconstruction plate with the spring plate, the spring plate with the variable angle plate, or when all three were compared together

*, **, ***, ns: significant at p-value ≤ 0.05, 0.01, 0.001, or not significant, respectively.

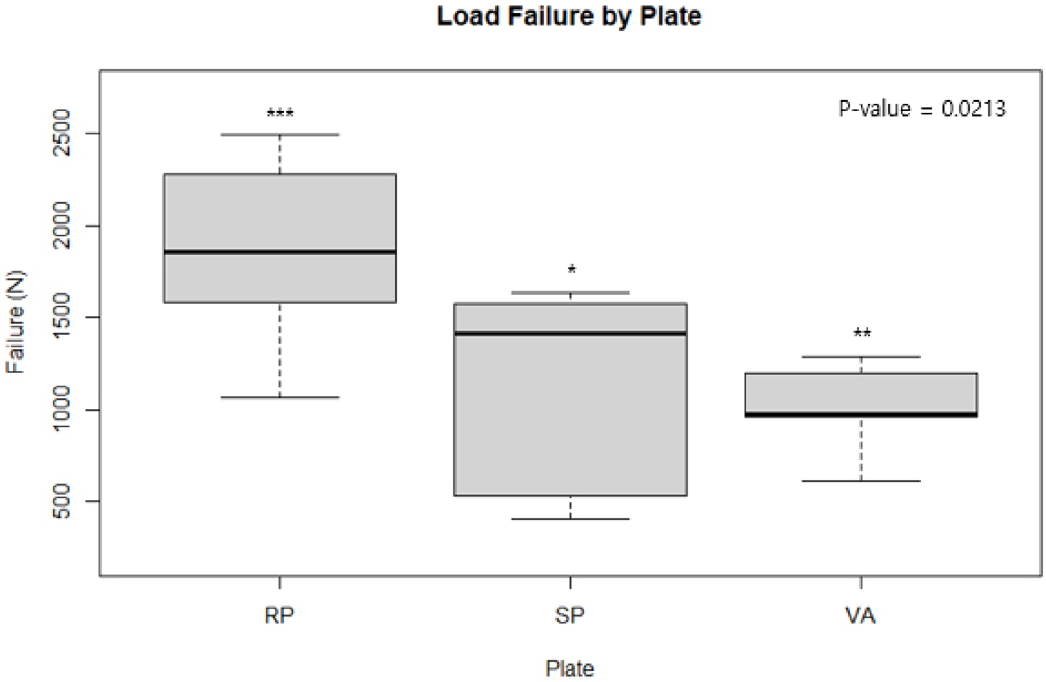

Figure 8. A qusai-static loading testing for each type of plate. Using quasi-static loading, we measured the force applied to each plate until mechanical failure, defined as the point at which the compression force and the plate's buttress force deviated from linear behavior. The conventional reconstruction plate demonstrated significant results against both the spring plate and the variable angle plate.

*, **, ***, ns: significant at p-value ≤ 0.05, 0.01, 0.001, or not significant, respectively.

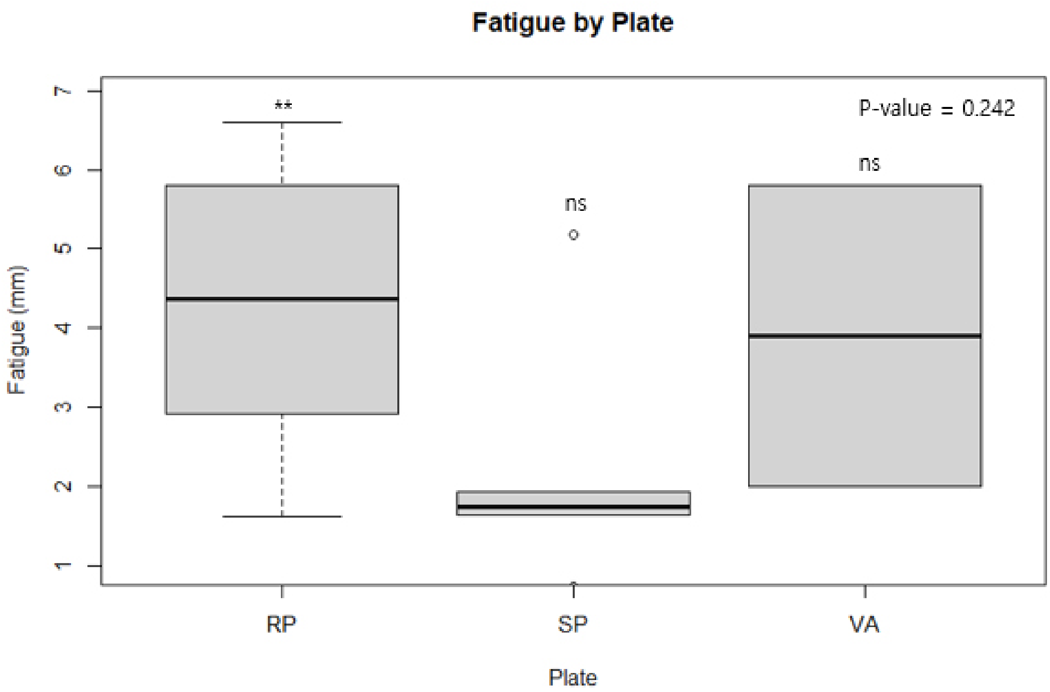

Figure 9. A fatigue study for each type of plate. The fatigue of the plate is defined as the difference between the gap at the endpoint and the starting point. The starting point is the difference between the gap at 1500 N and the gap at free load, while the endpoint is the difference in the interfragment gap at the end of 10,000 cycles and is set as the e value.

*, **, ***, ns: significant at p-value ≤ 0.05, 0.01, 0.001, or not significant, respectively.

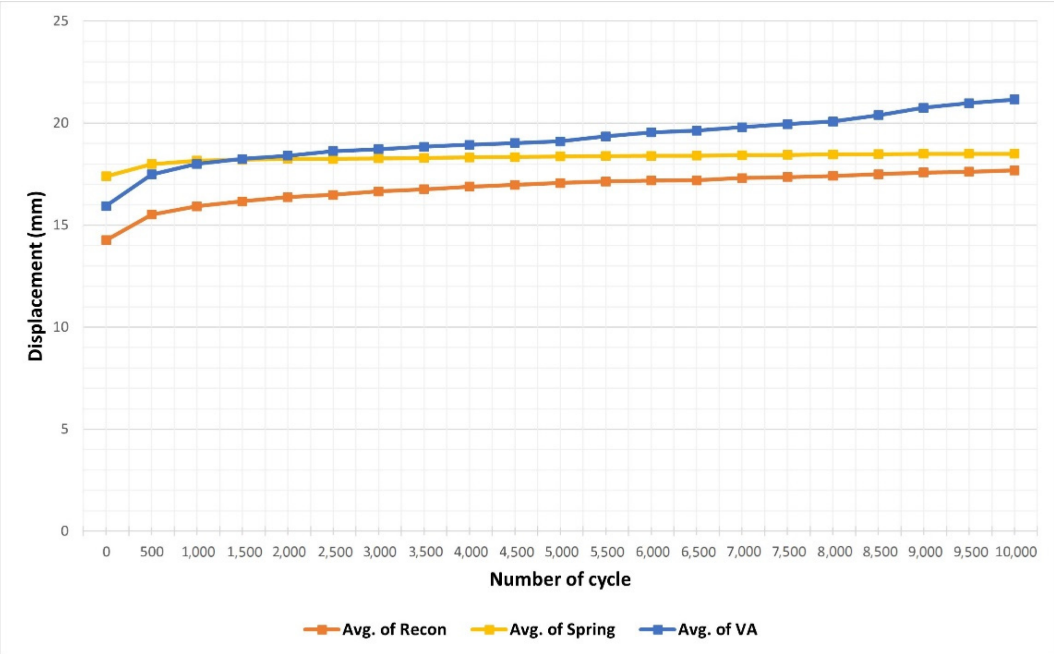

Figure 10. Average displacement of plates during the cyclic test. Each type of plate is subjected to a force of 1500 N over 10,000 cycles. We compared and analyzed the degree of displacement in 500 units of the cycle. In total, four hemipelves were used for each type of plate, but a failure occurred in one of the models of the spring plate, so the spring plate has only three results.

Table 1. The mean fracture gap observed in experiments

Group	Mean (mm)	SD*	SEM†
RP‡	2.37	1.04	0.42
SP§	2.51	1.42	0.63
VA‖	2.16	1.75	1.24

Group vs Group	*p* -value	95% CI¶
RP : SP	0.87	-1.93 – 1.67
RP : VA	0.89	-10.34 – 10.78
SP : VA	0.83	--7.47 – 8.18

* Standard Deviation
† Standard error of the mean
‡ Reconstruction plate.
§ Spring plate
‖ Variable angle plate
¶ Confidence Interval

Table 2. Load failure testing

Group	Mean (N)	SD*	SEM†
RP‡	1855.47	509.43	207.93
SP§	1111.79	592.6	264.55
VA‖	1007.72	260.85	116.45

Group vs Group	*p* -value	95% CI¶
RP : SP	0.05	-32.96 – 1520.31
RP : VA	0.01	293.98 – 1401.51
SP : VA	0.73	-620.57 – 828.72

* Standard Deviation
† Standard error of the mean
‡ Reconstruction plate.
§ Spring plate
‖ Variable angle plate
¶ Confidence Interval

4. Discussion

Posterior wall fractures are notably difficult to reduce and the success of surgical outcomes is heavily reliant on the quality of reduction rather than merely on the choice of fixation hardware [41-43]. Factors such as marginal impaction, femoral head chondral injury, and labral damage also significantly influence outcomes [44]. This study aimed to evaluate different reduction methods for the most commonly observed type of acetabular fractures. All fracture models were uniformly created and reduced without any instances of screw penetration, with variations solely based on the types of plates and screws used.

The conventional reconstruction plate demonstrated superior stiffness compared to the spring and variable angle plates, which showed no significant differences between them. Despite using screws of different diameters (2.7 mm for VA and 3.5 mm for spring plates), the strength and footprint size of the plates were comparable, suggesting that further investigation is needed to understand the impact of screw diameter on bone fixation strength.

In a secondary experiment, we subjected the same fracture model and fixation methods to a 10,000-cycle load of 1500 N, mimicking the force exerted by a 75 kg patient standing on one leg [45]. No significant differences were found among the groups, suggesting that under consistent load, the type of fixation does not compromise the stability of the implant during rehabilitation [46]. However, failures in cyclic testing were noted with the variable angle plate in older cadavers with osteoporotic bone, hinting at a potential reduction in fixation strength due to smaller screw diameters [26]. This underscores the necessity for further research into the effects of screw diameter on fixation strength in different bone qualities.

The fatigue analysis from cyclic testing did not reveal any significant differences in gap formation at the fracture site before and after testing, although gaps appeared during the cycles. For instance, the midpoint and endpoint gaps at the 10th and 9990th cycles showed fluctuations, which were statistically analyzed to assess the fatigue resistance of each plate. No significant differences in fatigue were observed, indicating that all plates maintained stability throughout the cycles, an important consideration for postoperative rehabilitation timing.

Furthermore, our study draws comparisons with previous studies such as by F. Pease [28], who evaluated different fixation strategies. Although Pease's study used Sawbones and showed different outcomes, the findings in our cadaver study suggest the need for additional research on the VA LCP plate, which might outperform traditional lag screws.

Clinical relevance is also supported by studies such as those by Abo Elsoud et al. and Kang et al., which have shown promising in vivo results for the stability of these plates, with most patients achieving union and excellent functional outcomes [47,48]. This is corroborated by our findings from the VA-LCP plate study [26], which also reported successful outcomes without complications.

However, the study faces limitations such as the variability in bone quality and the potential presence of osteoporosis in two hemipelvises, reflective of the aging population in Korea and the advanced age of the cadavers, which may compromise experimental validity. Additionally, the use of a saw to create the fracture model and direct loading via the Jig may not fully replicate clinical scenarios, potentially skewing results towards mechanical rather than clinical outcomes.

Despite these challenges, this study is the first biomechanical evaluation of the 2.7 mm LCP VA plate, providing valuable insights into the biomechanical performance of different fixation methods for posterior wall fractures. This contributes significantly to our understanding of these fractures and aids in improving surgical strategies for these complex injuries.

5. Conclusions

In conclusion, our findings demonstrate that while the conventional reconstruction plate exhibited superior stiffness, there were no significant differences in performance under cyclic loading conditions among the three plate types. This suggests that all three surgical options - conventional reconstruction, spring, and variable angle plates - provide sufficient stability for postoperative rehabilitation, assuming that patients avoid excessive activities. This study supports the continued use of the conventional reconstruction plate due to its proven stability, making it a reliable choice for surgical interventions. Additionally, the variable angle and spring plates also proved effective for fragment-specific fixation, ensuring adequate stability for these specific surgical procedures. Overall, each method has its merits, allowing for tailored surgical approaches based on patient needs and specific fracture characteristics.

References

1. Ochs, B.G.; Marintschev, I.; Hoyer, H.; Rolauffs, B.; Culemann, U.; Pohlemann, T.; Stuby, F.M. Changes in the treatment of acetabular fractures over 15 years: Analysis of 1266 cases treated by the German Pelvic Multicentre Study Group (DAO/DGU). Injury 2010, 41, 839–851.

2. Moed, B.R.; WillsonCarr, S.E.; Watson, J.T. Results of operative treatment of fractures of the posterior wall of the acetabulum. J. Bone Jt. Surg. Am. 2002, 84, 752–758.

3. Letournel, E.; Judet, R. Fractures of the Acetabulum; Springer Science & Business Media: Berlin, Germany, 2013.

4. Kumar, M.; Ahmed, M.; Hussain, G.; Saleem, M.; Sahar, K.; Bux, M. Frequency of posterior wall acetabular fracture in patients presenting with posterior hip dislocations. Rawal Med. J. 2020, 45, 347.

5. Moed, B.R.; Kregor, P.J.; Reilly, M.C.; Stover, M.D.; Vrahas, M.S. Current management of posterior wall fractures of the acetabulum. Instr. Course Lect. 2015, 64, 139–159. PMID: 25745901.

6. Vale, J.; Diniz, S.; Leite, P.S.; Soares, D. Surgical Treatment of Acetabular Posterior Wall Fracture with Hip Arthroscopy: A Case Report. Hip Pelvis 2022, 34, 62–67. https://doi.org/10.5371/hp.2022.34.1.62. PMID: 35355629; PMCID: PMC8931952.

7. Moed, B.R.; Ajibade, D.A.; Israel, H. Computed tomography as a predictor of hip stability status in posterior wall fractures of the acetabulum. J. Orthop. Trauma 2009, 23, 7–15.

8. Reagan, J.M.; Moed, B.R. Can computed tomography predict hip stability in posterior wall acetabular fractures? Clin. Orthop. Relat. Res. 2011, 469, 2035–2041.

9. Grimshaw, C.S.; Moed, B.R. Outcomes of posterior wall fractures of the acetabulum treated nonoperatively after diagnostic screening with dynamic stress examination under anesthesia. J. Bone Jt. Surg. Am. 2010, 92, 2792–2800.

10. Moed, B.R.; Willson Carr, S.E.; Gruson, K.I.; Watson, J.T.; Craig, J.G. Computed tomographic assessment of fractures of the posterior wall of the acetabulum after operative treatment. J. Bone Jt. Surg. Am. 2003, 85, 512–522.

11. Matta, J.M. Fractures of the acetabulum: Reduction accuracy and clinical results of fractures operated within three weeks of injury. J. Bone Jt. Surg. Am. 1997, 78, 1632–1645.

12. Olson, S.A.; Bay, B.K.; Pollak, A.N.; Sharkey, N.A.; Lee, T. The effect of variable size posterior wall acetabular fractures on contact characteristics of the hip joint. J. Orthop. Trauma 1996, 10, 395–402.

13. Moed, B.R.; Carr, S.E.W.; Watson, J.T. Open reduction and internal fixation of posterior wall fractures of the acetabulum. Clin. Orthop. Relat. Res. 2000, 377, 57–67.

14. Goulet, J.A.; Rouleau, J.P.; Mason, D.J.; Goldstein, S.A. Comminuted fractures of the posterior wall of the acetabulum. A biomechanical evaluation of fixation methods. J. Bone Jt. Surg. Am. 1994, 76, 1457–1463.

15. Zhang, Y.; Tang, Y.; Wang, P.; Zhao, X.; Xu, S.; Zhang, C. Biomechanical comparison of different stabilization constructs for unstable posterior wall fractures of acetabulum. A cadaveric study. PLoS ONE 2014, 8, e82993.

16. Zoys, G.N.; McGanity, P.L.; Lanctot, D.R.; Athanasiou, K.A.; Heckman, J.D. Biomechanical evaluation of fixation of posterior acetabular wall fractures. J. South. Orthop. Assoc. 1999, 8, 254–260.

17. Ferguson, T.A.; Patel, R.; Bhandari, M.; Matta, J.M. Fractures of the acetabulum in patients aged 60 years and older. J. Bone Jt. Surg. Br. 2010, 92, 250–257.

18. Schutz, M.; Sudkamp, N.P. Revolution in plate osteosynthesis: New internal fixator systems. J. Orthop. Sci. 2003, 8, 252–258.

19. Sommer, C.; Gautier, E.; Muller, M.; Helfet, D.L.; Wagner, M. First clinical results of the Locking Compression Plate (LCP). njury 2003, 34 (Suppl. S2), B43–B54.

20. Fulkerson, E.; Egol, K.A.; Kubiak, E.N.; Liporace, F.; Kummer, F.J.; Koval, K.J. Fixation of diaphyseal fractures with a segmental defect: A biomechanical comparison of locked and conventional plating techniques. J. Trauma 2006, 60, 830–835.

21. Frigg R. Locking Compression Plate (LCP). An osteosynthesis plate based on the Dynamic Compression Plate and the Point Contact Fixator (PC-Fix). Injury. 2001;32(suppl 2):63–66.

22. Tadros, A.M.A.; O'Brien, P.; Guy, P. Fixation of Marginal Posterior Acetabular Wall Fractures Using Locking Reconstruction Plates and Monocortical Screws. J. Trauma Inj. Infect. Crit. Care 2010, 68, 478–480.

23. Ebraheim, N.A.; Savolaine, E.R.; Hoeflinger, M.J.; Jackson, W.T. Radiological diagnosis of screw penetration of the hip joint in acetabular fracture reconstruction. J. Orthop. Trauma 1989, 3, 196–201.

24. Richter, H.; Hutson, J.J.; Zych, G. The Use of Spring Plates in the Internal Fixation of Acetabular Fractures. J. Orthop. Trauma 2004, 18, 179–181.

25. Lee, C.; Johnson, E.E. Use of Spring Plates in Fixation of Comminuted Posterior Wall Acetabular Fractures. J. Orthop. Trauma 2018, 32, S55–S59.

26. Cho, J.W.; Chung, H.J.; Kim, B.S.; Yeo, D.-H.; Song, J.-H.; Oh, C.-W.; Mauffrey, C.; Cho, W.-T.; Oh, J.-K. Fragment specific fixation technique using 2.7 mm VA LCP for comminuted posterior wall acetabular fractures: A novel surgical technique. Arch. Orthop. Trauma Surg. 2019, 139, 1587–1597. https://doi.org/10.1007/s00402-019-03236-1.

27. Al-Mukhtar, A.M.; Konke, C. Fracture Mechanics and Micro Crack Detection in Bone: A Short Communication. In Proceedings of the Medical Device Materials VI: Proceedings from the Materials and Processes for Medical Devices Conference, Minneapolis, MN, USA, 8–10 August 2011; p. 27776.

28. Pease, F.; Ward, A.; Stevenson, A.; Cunningham, J.; Sabri, O.; Acharya, M.; Chesser, T. Posterior wall acetabular fracture fixation: A mechanical analysis of fixation methods. J. Orthop. Surg. 2019, 27, 2309499019859838

29. Wu, X. A biomechanical comparison of different fixation techniques for fractures of the acetabular posterior wall. Int. Orthop. (SICOT) 2018, 42, 673–679.

30. Altun, G.; Saka, G.; Demir, T.; Elibol, F.K.E.; Polat, M.O. Precontoured buttress plate vs reconstruction plate for acetabulum posterior wall fractures: A biomech

31. Mast, J.; Jakob, R.; Ganz, R. Planning and Reduction Technique in Fracture Surgery; Springer: New York, NY, USA, 1989.

32. Fracture and Dislocation Compendium. Orthopaedic Trauma Association Committee for Coding and Classification. J. Orthop. Trauma 1996, 10 (Suppl. S1), 1–154.

33. Cho, J.W.; Cho, W.T.; Sakong, S.; Lim, E.J.; Choi, W.; Kang, S.; Kim, B.-S.; Kim, J.-K.; Oh, C.-W.; Oh, J.-K. Mapping of acetabular posterior wall fractures using a three-dimensional virtual reconstruction software. Injury 2021, 52, 1403–1409.

34. Moed, B.R.; McMichael, J.C. Outcomes of posterior wall fractures of the acetabulum. Surgical technique. J. Bone Jt. Surg. Am. 2008, 90 Pt 1 (Suppl. S2), 87–107.

35. Woo, S.H.; Sung, M.J.; Park, K.S.; Yoon, T.R. Three-dimensional-printing technology in hip and pelvic surgery: Current landscape. Hip Pelvis 2020, 32, 1–10

36. Dessouki, O.; Samiezadeh, S.; Bougherara, H.; Zdero, R.; Schemitsch, E. Biomechanics of Acute Total Hip Arthroplasty after Acetabular Fracture: Plate vs Cable Fixation; Orthopaedic Research Society (ORS): Las Vegas, NV, USA, 2015.

37. Scannell, B.P.; Loeffler, B.J.; Hoenig, M.; Peindl, R.D.; D'Alessandro, D.F.; Connor, P.M.; Fleischli, J.E. Biomechanical comparison of hamstring tendon fixation devices for anterior cruciate ligament reconstruction: Part 1. Five femoral devices. Am. J. Orthop. 2015, 44, 32–36.

38. Whittle, M.W. Gait Analysis and Introduction, 4th ed.; Butterworth-Heinemann: Oxford, UK, 2007

39. Feng, X.; Zhang, S.; Luo, Q.; Fang, J.; Lin, C.; Leung, F.; Chen, B. Definition of a safe zone for antegrade lag screw fixation of fracture of posterior column of the acetabulum by 3D technology. Injury 2016, 47, 702–706.

40. Barnett, V.; Lewis, T. Outliers in Statistical Data; Wiley: New York, NY, USA, 1994; Volume 3, No. 1.

41. Kim, H.T.; Ahn, J.M.; Hur, J.O.; Lee, J.S.; Cheon, S.J. Reconstruction of acetabular posterior wall fractures. Clin. Orthop. Surg. 2011, 3, 114–120. https://doi.org/10.4055/cios.2011.3.2.114. PMID: 21629471; PMCID: PMC3095781.

42. Tannast, M.; Najibi, S.; Matta, J.M. Two to twenty-year survivorship of the hip in 810 patients with operatively treated acetabular fractures. J. Bone Jt. Surg. Am. 2012, 94, 1559–1567.

43. Clarke-Jenssen, J.; Røise, O.; Storeggen, S.; Madsen, J.E. Long-term survival and risk factors for failure of the native hip joint after operatively treated displaced acetabular fractures. Bone Jt. J. 2017, 99, 834–840.

44. Moed, B.R.; McMahon, M.J.; Armbrecht, E.S. The acetabular fracture prognostic nomogram: Does it work for fractures of the posterior wall? J. Orthop. Trauma 2016, 30, 208–212.

45. Baumgaertner, M.R. Fractures of the posterior wall of the acetabulum. J. Am. Acad. Orthop. Surg. 1999, 7, 54–65.

46. Giannoudis, P.V.; Kanakaris, N.K.; Sante, E.D.; Morell, D.J.; Stengel, D.; Prevezas, N. Acetabular fractures with marginal impaction. Bone Jt. J. 2013, 95, 230–238.

47. Abo-Elsoud, M.; Kassem, E. Fragment-specific fixation of posterior wall acetabular fractures. Int. Orthop. (SICOT) 2021, 45, 3193–3199.

48. Kang, J.H.; Lee, S.H.; Lee, H.J. Usefulness of Spring Plate for Acetabular Posterior Wall Fracture Including Small Fragment. J. Korean Fract. Soc. 2016, 29, 19–25. https://doi.org/10.12671/jkfs.2016.29.1.19.

Abstract in Korean

사체 연구를 통한 골반골 비구 후벽 골절의 고정법의 생역학적 연구

비구 골절은 비교적 드물게 발생하지만 고에너지 외상과 연관되어 치료에 상당한 어려움을 초래하며 예후도 좋지 않은 경우가 많습니다. 이 중 비구 후벽 골절은 가장 흔한 유형으로 다른 유형에 비해 예후가 비교적 양호한 편입니다. 후벽의 해부학적 정복을 통한 연골의 회복과 안정적인 고정은 최적의 치료 결과를 얻기 위한 필수적인 요건입니다.

본 연구는 비구 후벽 골절에 대한 세 가지 주요 고정 방법(재건 플레이트, 스프링 플레이트, 2.7mm 가변 각도 잠금 압박 플레이트)의 생체역학적 성능을 비교하는 것을 목적으로 합니다. 연구에는 6 구의 신선 동결 사체가 사용되었으며 이전에 외상이나 수술 병력이 없는 12 개의 반골반을 분석 대상으로 하였습니다. 단순 비구 후벽 골절 모델을 이용해 세 가지 고정 방법을 비교하였으며 한 명의 정형외과 전문의가 플레이트 고정을 시행하였습니다. 반골반은 준정적 및 반복 하중 테스트를 통해 골절 간격, 강성 및 하중 조건에서의 변위를 측정하였습니다. 반복 하중 조건에서는 세 가지 고정 방법 간 골절 간격에서 유의미한 차이가 나타나지 않았습니다. 그러나 제건 플레이트는 스프링 플레이트는 스프링 플레이트와 가변 각도 잠금 압박 플레이트보다 더 높은 강성을 보였습니다. 피로 분석 결과, 세 가지 플레이트 간 유의미한 차이는 나타나지 않았으며 반복 하중 조건에서도 유사한 안정성을 보였습니다. 강성의 차이에도 불구하고, 세 가지 고정 방법 모두 하중 조건에서 적절한 안정성을 입증하였습니다.

본 연구 결과는 비구 후벽 골절에 대한 다양한 고정 방법의 생체역학적 성능 이해에 기여하며, 복잡한 수술에서 플레이트 선택의 다양성에 도움을 줄 수 있습니다.

핵심되는 말 : 생역학적 연구, 비구, 후벽 골절, 가변 각도 플레이트