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Research article

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Maintenance of acetabular correction following PAO: a multicenter study comparing stainless-steel and titanium screws

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ABSTRACT

Stainless-steel screws are commonly used for fragment fixation during periacetabular osteotomy (PAO) at our institutions. Titanium is reserved for patients with documented nickel allergies. Titanium screws possess a significantly lower Young's modulus than stainless steel and, therefore, potentially less resistance to physiologic loading. Thus, we hypothesized that the use of titanium screws might be associated with changes in acetabular correction prior to healing. The aim of this study was to compare the maintenance of acetabular correction following PAO using stainless-steel or titanium screws. A documented nickel allergy was confirmed with an allergy specialist. Patients' age at surgery, gender and BMI were collected. The lateral center–edge angle of Wiberg (LCEA), medial center–edge angle (MCEA), anterior wall index (AWI), posterior wall index (PWI) and Tönnis angle were measured. The delta value for radiographic parameters was calculated as the difference between values immediately post-operation and at 6 months post-operation. Only age at surgery ($P < 0.001$) and the pre-operative LCEA ($P = 0.013$) were significantly different between groups (Tables I and II). The remaining pre- and post-operative radiological measurements were similar (Table II). Comparison of delta values at 6 months follow-up indicated no significant differences between screw types (Table III). No patients in the titanium group had a trans-iliac retrograde screw included in their construct ($P = 0.003$). All patients healed from their osteotomies. The use of titanium screws in patients with an allergy to nickel was not associated with differences in acetabular correction or the rate of osseous union rates despite its lower inherent mechanical properties.

INTRODUCTION

Hip dysplasia is characterized by the insufficient coverage of the femoral head by an excessively shallow acetabulum. Symptomatic acetabular dysplasia is commonly treated with periacetabular osteotomy (PAO) [1]. During a PAO procedure, the acetabulum is repositioned to improve the coverage of the femoral head in order to improve the stability of the hip joint. The PAO surgery reliably and reproducibly improves hip function, decreases hip pain and delays the need for total hip arthroplasty in the majority of patients [1, 2]. Moreover, PAO can improve symptoms from pathologic acetabular retroversion or anteversion [3, 4]. During PAO surgery, osteotomies are performed surrounding the acetabulum until it is free from the remainder of the pelvis. The acetabulum then reoriented into the desired position of correction and fixed into place. Usually, three or more screws are used to hold the acetabulum in its new position. Over time, the osteotomy sites heal, fusing the acetabular fragment to the rest of the pelvis.

Two types of screws are commonly used for fixation during in PAO. These include solid fully threaded stainless-steel screws and solid fully threaded titanium screws in those with concerns for significant nickel allergies. The moduli of stainless-steel screws and titanium screws differ considerably, with the titanium screws possessing a lower Young's modulus and, therefore, less resistance to physiologic forces and loading after placement *in vivo* [5]. We, therefore, hypothesized that the use of titanium screws for fixation during PAO might be associated with changes in acetabular correction prior to healing. The aim of the current study was to compare the maintenance of acetabular correction following PAO between stainless-steel and titanium screws.

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MATERIALS AND METHODS

Demographics

We performed a retrospective study of 144 patients (154 hips) with a primary diagnosis of hip dysplasia undergoing PAO at our institutions between January 2018 and April 2022. The study was approved by the Institutional Review Board (IRB ID: 2022-0606, 17-0741). Inclusion criteria were patients undergoing PAO with pre- and post-operative radiological imaging (standardized, anterior–posterior pelvis radiographs) and at least 6 months follow-up. Patients' age at surgery, gender and BMI were collected. The indication for the use of titanium screws was an allergy to nickel confirmed by evaluation with an allergy specialist. Pre-operative screening and or confirmatory testing was routinely obtained and or documented prior to surgery in all patients.

Surgical technique of PAO

PAO is performed similar to the original technique of Ganz *et al.* [6]. The authors performed the approach through the Smith-Petersen interval using a standard bikini incision and perform the ramus osteotomy first, followed by the ischial, iliac and posterior column osteotomies in sub-periosteal fashion. The fragment is then mobilized and checked for appropriate coverage, version and position following temporary fixation using fluoroscopy with or without image assistance. The fragment is then fixed in the desired position with the appropriate final screw construct, and the final films are obtained. The incision is then closed, and a sterile dressing is applied. Previously described surgical complications following PAO include nerve injury, wound infection, vascular injury, non-unions and conversion to total hip replacement [7]. The post-operative rehabilitation programs include weight-bearing precautions and physical therapy similar to those previously described [8].

Radiological assessment

Based on standardized, anterior–posterior pelvis radiographs, the lateral center–edge angle of Wiberg (LCEA), medial center–edge angle (MCEA) and Tönnis angle were measured by Merge PACS Workstation before and after the PAO [9, 10]. Anterior wall index (AWI) and posterior wall index (PWI) were measured using established methodology [11].

Outcome assessment

The number of screws was recorded. Post-operative LCEA, MCEA, Tönnis angle, AWI and PWI were also collected immediately post-operation and at 6 months post-operation. The delta value for radiographic parameters (value evaluated at 6 month post-operation – value evaluated at immediate post-operation) were calculated and compared between groups.

Statistical analysis

Continuous variables are summarized as means with SDs or medians with first and third quartiles (Q1 and Q3, respectively), depending on the distribution of the data. Categorical variables are expressed in frequency (percentage). Differences between continuous variables were analyzed using Student's t-test (normal distribution) and Mann–Whitney U test (non-normal distribution). For categorical variables, the chi-square test was used to determine statistical differences. All of the analyses were performed using the R software (version 4.2.0, http://www.R-project.org, The R Foundation). A P-value < 0.05 (two-sided) was considered statistically significant.

Table I. ***Patients' baseline characteristics***

Screw type	*Stainless*	*Titanium*	*P value*
N (Hips)	132	22	
Age at surgery	17.02 ± 3.84	21.50 ± 7.22	<0.001
BMI	23.16 ± 4.56	23.27 ± 4.07	0.916
Laterality = Right (%)	74 (56.06%)	13 (59.09%)	0.974
Sex = Female (%)	119 (90.15%)	22 (100.00%)	0.261

RESULTS

The patients' baseline characteristics are shown in Table I. There were 132 total hips in the stainless-steel group and 22 total hips in the titanium group. All included screws were solid, 4.5-mm screws. Differences in statistical significance were detected in comparison to age at surgery ($P < 0.001$). No significant difference was observed between the two groups for BMI ($P = 0.916$), sex ($P = 0.261$) or laterality ($P = 0.974$).

The results of comparison of pre- and post-operative radiological measurements are shown in Table II. For the comparison of pre-operative radiological measurements, there was no significant difference observed between the two groups for MCEA ($P = 0.364$), Tönnis angle ($P = 0.054$), AWI ($P = 0.323$) and PWI ($P = 0.239$). There was a difference between groups for the preoperative LCEA ($P = 0.013$). Additionally, no significant difference was observed between the two groups for immediate post-operative radiological measurements, including LCEA ($P = 0.379$), MCEA ($P = 0.160$), Tönnis angle ($P = 0.202$), AWI ($P = 0.671$) and PWI ($P = 0.208$). The percentage of cases fixed with three screws was higher in the titanium group ($P = 0.047$). No patients in the titanium group had a trans-iliac retrograde screw included in their construct ($P = 0.003$). No significant differences were observed between the two groups for delta LCEA ($P = 0.058$), delta MCEA ($P = 0.733$), delta Tönnis angle ($P = 0.268$), delta AWI ($P = 0.114$) and delta PWI ($P = 0.388$), Table III. Thus, no significant change in fragment position was observed between groups.

DISCUSSION

PAO is the established surgical treatment for symptomatic hip instability secondary to acetabular dysplasia and reliably preserves the structure and function of the native hip. Two types of solid, fully threaded screws are currently used for fixation in this procedure, stainless-steel and titanium. Due to their inherent differences in Young's elastic modulus, the risk of loss of correction when using titanium screws for fixation of the acetabular fragment following prior to union of the fragment and pelvis following PAO could be significant. As a result of these concerns, we sought to determine if the positioned fragment changed when using titanium screws compared with stainless-steel screws, following PAO. To our knowledge, no clinical study has investigated the maintenance of acetabular correction between these two types of screws. The current study provides evidence for the

Table II. ***The comparison of pre- and post-operative radiological measurements***

Screw type	*Stainless*	*Titanium*	*P value*
N (Hips)	132	22	
Pre-operative LCEA	14.54 ± 9.82	19.91 ± 4.17	0.013
Pre-operative MCEA	42.73 ± 12.15	40.32 ± 6.23	0.364
Pre-operative Tönnis angle	15.64 ± 7.94	12.18 ± 6.17	0.054
Pre-operative AWI	0.33 ± 0.14	0.36 ± 0.08	0.323
Pre-operative PWI	0.98 ± 0.23	0.91 ± 0.14	0.239
Post-operative LCEA	32.14 ± 5.64	33.23 ± 3.16	0.379
Post-operative MCEA	33.01 ± 6.90	30.73 ± 7.69	0.160
Post-operative Tönnis angle	3.26 ± 3.58	4.27 ± 2.41	0.202
Post-operative AWI	0.46 ± 0.14	0.48 ± 0.10	0.671
Post-operative PWI	0.96 ± 0.23	0.90 ± 0.19	0.208

Table III. The comparison of radiographic outcomes

Screw type	*Stainless*	*Titanium*	*P value*
N (Hips)	132	22	
Screw number			0.047
3	61 (46.21%)	17 (77.27%)	
4	56 (42.42%)	5 (22.73%)	
5	11 (8.33%)	0 (0.00%)	
6	4 (3.03%)	0 (0.00%)	
Number of cases without a trans-iliac screw (%)	93 (70.45%)	22 (100.00%)	0.003
Delta LCEA	−0.01 ± 2.16	−1.00 ± 2.43	0.058
Delta MCEA	−0.51 ± 3.15	−0.77 ± 4.15	0.733
Delta Tönnis angle	−0.16 ± 2.40	−0.76 ± 1.48	0.268
Delta AWI	−0.05 ± 0.10	−0.02 ± 0.07	0.114
Delta PWI	0.08 ± 0.15	0.05 ± 0.10	0.388

use of titanium screws in patients undergoing PAO, especially in those who are allergic to nickel. Our findings indicate that the radiographic outcomes of patients who underwent fixation with titanium screws were comparable to those using stainless-steel screws.

Advantages of titanium include good biocompatibility, light weight, good resistance to corrosion and a Young's modulus of elasticity (20 GPa) similar to that of bone to prevent stress shielding [12]. Thus, titanium has been widely used in orthopedic operations, including total joint replacement and fracture fixation [13–16]. Compared with stainless steel, titanium has a lower Young's modulus (110 GPa versus 190 GPa), which means that titanium has a lower stiffness. Thus, we hypothesized that titanium screws might not maintain acetabular correction prior to healing after PAO when compared with stainless-steel screws due to their inferior mechanical properties. Our results indicate that the delta values between the two groups of patients are similar, demonstrating that the maintenance of acetabular correction following PAO in patients using titanium screws is comparable to those using stainless-steel screws at 6 months follow-up, despite titanium's lower stiffness. The stability of titanium screws has been previously studied in an *in vitro* biomechanical study after curved PAO, which indicated that the fixation with titanium screws provided sufficient stability compared with bioabsorbable screws [17].

It is important to note that titanium implants have been shown to continuously release titanium particles in the body, leading to damage to intraepithelial homeostasis and inflammation in the surrounding tissues [18]. The mechanisms seem to be associated with the damage to the cytoskeleton of bone marrow mesenchymal stem cells and the activation of macrophages and neutrophils [19–21]. Despite these prior findings, we did not observe a difference in osseous union in a relatively young, healthy patient population undergoing PAO. However, both institutions have observed that titanium screws tend to break more easily upon removal and extra care ought to be taken to remove any excess bone surrounding the screw head prior to the attempted removal.

There are several limitations to the present study. First, randomization was not used in this study. Titanium screws were used only in patients with a documented nickel allergy confirmed by an allergy specialist. Second, the follow-up time is relatively short but includes patients followed to union, which is the time of interest pertinent to the study question. All patients achieved radiographic union at 6 months post-operatively. Third, skewed sample distribution between the two groups (132 versus 22) reduced the power of the study to draw meaningful conclusions. The power analysis suggested that the power is 0.46, 0.06, 0.25, 0.32 and 0.17 for delta LCEA, delta MCEA, delta Tönnis angle, delta AWI and delta PWI, respectively, which were all lower than the ideal power 0.8. The lower power indicates a higher risk of type II error, meaning a failure to detect a true effect when it exists. More samples are needed in our further study. Despite these limitations, the current study is still of great importance as this is the first study that compares the maintenance of fragment position until osseous union following fixation with stainless-steel or titanium screws during PAO.

CONCLUSION

The current study demonstrates that the maintenance of acetabular correction following PAO was comparable between patients using stainless-steel and titanium screws. The use of titanium screws in patients with an allergy to nickel was not associated with an increased risk of significant change in fragment position despite its lower inherent mechanical properties. Our findings provide evidence to support the further use of solid, fully threaded, titanium screws in patients undergoing PAO with a nickel allergy.

DATA AVAILABILITY

The data underlying this article will be shared on reasonable request to the corresponding author.

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CONFLICT OF INTEREST STATEMENT

None declared.

REFERENCES

1. Harris JD, Lewis BD, Park KJ. Hip dysplasia. *Clin Sports Med* 2021; **40**: 271–88.
2. Gala L, Clohisy JC, Beaule PE. Hip dysplasia in the young adult. *J Bone Joint Surg Am* 2016; **98**: 63–73.
3. Tibor LM, Sink EL. Periacetabular osteotomy for hip preservation. *Orthop Clin North Am* 2012; **43**: 343–57.
4. Clohisy JC, Barrett SE, Gordon JE *et al.* Periacetabular osteotomy in the treatment of severe acetabular dysplasia. *J Bone Joint Surg Am* 2006; **88**: 65–83.
5. Niinomi M, Liu Y, Nakai M *et al.* Biomedical titanium alloys with Young's moduli close to that of cortical bone. *Regen Biomater* 2016; **3**: 173–85.
6. Ganz R, Klaue K, Vinh TS *et al.*. A new periacetabular osteotomy for the treatment of hip dysplasias. Technique and preliminary results. *Clin Orthop Relat Res* 1988; **232**: 26–36.
7. Ali M, Malviya A. Complications and outcome after periacetabular osteotomy - influence of surgical approach. *Hip Int* 2020; **30**: 4–15.
8. Disantis AE, Ruh E, Martin R *et al.* Rehabilitation guidelines for use following a periacetabular osteotomy (PAO): a North American based Delphi consensus. *Int J Sports Phys Ther* 2022; **17**: 1002–15.
9. Davila-Parrilla AD, Wylie J, O'Donnell C *et al.* Reliability of and correlation between measurements of acetabular morphology. *Orthopedics* 2018; **41**: e629–e35.
10. Wiberg G. Studies on the dysplastic acetabula and congenital subluxation of the hip joint. *Acta Chir Scand* 1939; **58**: 5–135.
11. Siebenrock KA, Kistler L, Schwab JM *et al.* The acetabular wall index for assessing anteroposterior femoral head coverage in symptomatic patients. *Clin Orthop Relat Res* 2012; **470**: 3355–60.
12. Kaur M, Singh K. Review on titanium and titanium based alloys as biomaterials for orthopaedic applications. *Mater Sci Eng C Mater Biol Appl* 2019; **102**: 844–62.
13. Kim JK, Park IW, Ro DH *et al.* Is a titanium implant for total knee arthroplasty better? A randomized controlled study. *J Arthroplasty* 2021; **36**: 1302–9.
14. Jauregui JJ, Banerjee S, Cherian JJ *et al.* Early outcomes of titanium-based highly-porous acetabular components in revision total hip arthroplasty. *J Arthroplasty* 2015; **30**: 1187–90.
15. Wall EJ, Jain V, Vora V *et al.* Complications of titanium and stainless steel elastic nail fixation of pediatric femoral fractures. *J Bone Joint Surg Am* 2008; **90**: 1305–13.
16. Naziri Q, Issa K, Pivec R *et al.* Excellent results of primary THA using a highly porous titanium cup. *Orthopedics* 2013; **36**: e390–4.
17. Kashima N, Shiramizu K, Nakamura Y *et al.* Biomechanical comparison of the fixation after curved periacetabular osteotomy using titanium and bioabsorbable screws. *Hip Int* 2015; **25**: 164–7.
18. Zhou Z, Shi Q, Wang J *et al.* The unfavorable role of titanium particles released from dental implants. *Nanotheranostics* 2021; **5**: 321–32.
19. Bressan E, Ferroni L, Gardin C *et al.* Metal nanoparticles released from dental implant surfaces: potential contribution to chronic inflammation and peri-implant bone loss. *Materials (Basel)* 2019; **12**: 1–26.
20. Obando-Pereda GA, Fischer L, Stach-Machado DR. Titanium and zirconia particle-induced pro-inflammatory gene expression in cultured macrophages and osteolysis, inflammatory hyperalgesia and edema in vivo. *Life Sci* 2014; **97**: 96–106.
21. Pajarinen J, Kouri VP, Jamsen E *et al.* The response of macrophages to titanium particles is determined by macrophage polarization. *Acta Biomater* 2013; **9**: 9229–40.