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# Midterm Results of Total Hip Arthroplasty Using a Delta Ceramic Liner with a Titanium Taper Locking Band

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**Background:** This retrospective midterm study aimed to analyze seating properties, fracture types, noisy hips, and survivorship of a delta ceramic liner with a titanium taper locking band.

**Methods:** A total of 451 patients (538 hips) underwent cementless total hip arthroplasty using the same design delta ceramic liner. Patients' clinical functions were evaluated using Harris Hip score, and the radiological migration or loosening of cementless cups was recorded. Component survival was evaluated by Kaplan-Meier survivorship analysis, with failure defined as revision of any component or ceramic bearing for any reason. The worst-case survival scenario for noisy hip revision recommendations was estimated.

**Results:** A total of 475 patients (514 hips) were evaluated with an average follow-up of 9.5 years (range, 5–13.9 years). One hip (0.19%) had intraoperative asymmetric seating. No hips had loosening, osteolysis, wear, or delta ceramic liner or head fracture. Three patients (0.58%) reported reproducible squeaking. Two cups were revised due to recurrent dislocation, 2 femoral stems were revised for periprosthetic fractures, and 1 hip was treated for deep periprosthetic joint infection. Kaplan-Meier survivorship analysis showed a 10-year cup survival rate of 97.8% (95% CI, 95.2%–99.9%), with any revision as the endpoint. The worst-case scenario showed a 10-year survival rate of 96.4% (95% CI, 94.2%–99.2%).

**Conclusions:** The Delta ceramic liner with a titanium locking band on the mutlibearing cementless cup offered secure intraoperative seating properties with fewer ceramic-related complications at the midterm follow-up.

**Keywords:** *Hip, Total hip arthroplasty, Ceramic-on-ceramic*

Wear and osteolysis remain the primary main causes of revision surgeries in total hip arthroplasty (THA).[1,2] Bearing technology continues to improve and offer new solutions for these surface problems. The current bearing surface combinations include metal-on-polyethylene (MoP), zirconium/oxinium on polyethylene and ceramic-on-polyethylene, which are based on cross-linked polyethylene, and ceramic-on-ceramic (CoC).[3] Among these surface groups, contemporary CoC articulations feature the lowest wear rate.[4] Second- and third-generation ceramic surfaces are characterized by improved mechanical properties, such as a lower friction coefficient, compared to MoP-based bearing couples, but higher ceramic fracture rates and noisy hips continue to represent major concerns for these materials.[5]

The lowest fracture rates for ceramic components have been reported for the main manufacturer: 0.032% for

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forte liners, 0.021% for forte heads, 0.028% for delta liners, and 0.002% for delta heads.[6] However, the ceramic fracture rates for the third-generation forte liners have been reported in the range of 0%–3.6%.[2] By contrast, the delta ceramic fracture rates have ranged from 0% to 0.9%.[7] In a recent meta-analysis, the estimated liner fracture rates for the forte and delta heads were almost equal at 0.2% (0.5/1,000 patient-years).[8]

The occurrence of delta ceramic liner fractures is not directly associated with the mechanical properties of the ceramic material. The increased delta head diameter and the decreased calculated thickness of the delta liner have also not been directly associated with fracture occurrence.[6] The malseating of the liner has been identified as the primary risk factor for central-type liner fractures, and the use of an inner taper metal shell or a titanium-backing sleeve can increase the risk of liner malseating, according to some reports.[9] The inner taper angle of the acetabular metal shell can also affect the incomplete or malseating of the ceramic liner and may lead to subsequent ceramic liner fracture.[10]

The purpose of this study was to analyze the seating properties of the delta liner with a titanium taper locking band in a multi-bearing cementless cup, the rate of delta ceramic head or liner fractures, noisy hips, and survival of the cementless cup for midterm follow-up.

## METHODS

We conducted this study with the principles of the Declaration of Helsinki. This reseach protocol was approved by the Institutional Review Board of the Acıbadem Mehmet Ali Aydinlar University Faculty of Medicine (IRB No. ATADEK 2016-8/17). Written informed consent was obtained from all participants.

We identified a series of 498 patients (538 hips) who underwent primary THA with delta-on-delta ceramic bearings between December 2009 and June 2018. After excluding 23 patients (24 hips, 4.4% of the total cohort) lost to follow up, the remaining 475 patients (514 hips) were evaluated, with an average follow-up period of 9.5 years (range, 5–13.9 years) (Fig. 1). The population consisted of 132 men and 343 women, with a mean age of 58.8 years (range, 28–80 years). The mean body mass index (BMI) was 28.6 kg/m$^2$ (range, 20.9–41.7 kg/m$^2$). The preoperative indications for primary THA and the patients' demographics are listed in Table 1.

All surgical procedures were performed using a direct posterior approach, with a posterior capsule and short external rotator repair using intraosseous sutures. All patients received prophylactic antibiotics to prevent infection, and low-molecular-weight heparin and elastic compression stockings were applied to prevent deep vein thrombosis. All patients were mobilized on postoperative day 1 and were allowed tolerated weight-bearing, except patients who underwent femoral shortening osteotomy in high dislocated hips.

All patients underwent THA with a cementless acetabular cup (R3 hemispherical, porous-coated acetabular shell [Smith and Nephew]), which had an 18° inner taper locking angle, and 28-, 32-, and 36-mm delta CoC articulations (BIOLOX delta; CeramTec). The diameter of the ceramic bearing was 28 mm for multibearing shells from 42 to 46 mm, 32 mm for metal shells from 48 to 50 mm, and 36 mm for metal shells ≥ 52 mm. The primary THA used one of the following stems: cementless triple-taper Polar stem , Anthology porous femoral stem, SL-Plus stem, ADR conical stem, CPCS (all of them; Smith & Nephew),

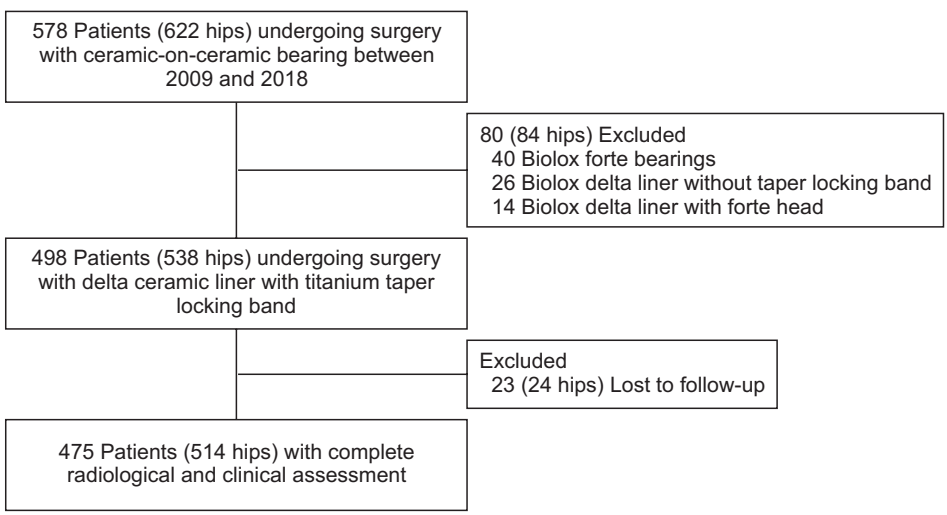


**Fig. 1.** Study cohort flowchart.

**Table 1.** Preoperative and Intraoperative Demographics of Patients

| Variable | Value |
|---|---|
| Age (yr) | 58.8 ± 10.7 |
| Body mass index (kg/m$^2$) | 28.6 ± 3.2 |
| Cup inclination | 31.5 ± 6.2 |
| Cup anteversion | 19.5 ± 8.3 |
| Etiology | |
| Coxarthrosis | 298 (58.1) |
| Dysplasia | 82 (16.0) |
| Osteonecrosis | 70 (13.6) |
| Posttrauma arthrosis | 27 (5.2) |
| Rheumatologic | 18 (3.5) |
| Others | 19 (3.6) |
| Head type | |
| 28 mm | 10 (2) |
| 32 mm | 144 (28) |
| 36 mm | 360 (70) |
| Head offset | |
| Short | 371 (72.2) |
| Medium | 105 (20.4) |
| Long | 38 (7.4) |
| Stem type | |
| Polar stem-standard | 275 (53.5) |
| Polar stem-lateralized | 138 (26.8) |
| Anthology-standard | 36 (7.1) |
| Anthology-lateralized | 28 (5.4) |
| Others | 37 (7.2) |

Values are presented as mean ± standard deviation or number (%).

Corail (Depuy), or CDH porous stem (Biomet) (Table 2).

Clinical and radiological evaluations were performed preoperatively and postoperatively, after 3 months, 6 months, 1 year, 3 years, and 5 years, and the clinical outcomes were evaluated. The anteroposterior and lateral radiographs obtained at the 3-month follow-up were used as the baseline for radiological evaluations. Evidence of acetabular and femoral component loosening was reviewed.[11,12] The clinical outcomes were evaluated using the Harris hip score (HHS).[13] Stem osseointegration was graded as stable with bony ingrowth, stable fibrous, or loose, according to Engh et al.[14] The acetabular cup stability was evaluated using the method described by Latimer and Lachiewicz,[15] and > 2-mm cup migration or > 4° change in cup inclination angle was defined as loosening. Two observers, who were not directly involved in the index surgeries (KK and GD), assigned the clinical scores and performed the radiological evaluations.

The abduction and anteversion angles of the cementless cup were calculated on postoperative radiographs taken 3 months after surgery.[16] Any step-off between the titanium band of the ceramic liner and the metal shell was categorized as a malseated liner on the immediate postoperative and follow-up radiographs. When any radiopaque particles appeared on follow-up radiographs, the fracture of the ceramic liner was suspected, and/or when squeaking was reported or noted at follow-up, computed tomography scans were used to evaluate any suspected malseating or fracture of the ceramic liner. The postoperative characteristics of noisy hips were noted at each follow-up.

Statistical analysis was performed using MedCalc statistical software version 17.9 (MedCalc Software bvba; https://www.medcalc.org; 2017). The survival of the components was calculated using Kaplan-Meier survivorship analysis, and failure was defined as any component revision for any reason. A worst-case scenario was estimated based on the assumption that all patients with noisy hips

**Table 2.** Detailed Review of Noisy Hips with Titanium Locking Band Liner

| No | Etiology | Noise type | Ceramic liner size | Ceramic head type & offset | Acetabular inclination (°) | Acetabular version (°) | First presentation of noise during FU | Revision |
|---|---|---|---|---|---|---|---|---|
| 1 | Type I DDH | Squeaking | 52 | 36 Short | 42 | 33.4 | 72 | Recommended |
| 2 | Posttrauma | Squeaking | 50 | 32 Short | 46.7 | 40.7 | 71 | Recommended |
| 3 | Coxarthrosis | Squeaking | 48 | 32 Short | 55 | 45.2 | 32 | Recommended |
| 4 | Coxarthrosis | Click | 52 | 36 Medium | 26.8 | 39.6 | 6 | Conservative FU |

Acetabular inclination and asetabular version were measured in computed tomography.
FU: follow-up, DDH: developmental dysplasia of the hip.

were recommended for revision. HHS values were compared with the Student *t*-test. The possible determinants of noisy hips were evaluated using multiple regression analysis, which included patient demographics (age, diagnosis, and BMI), radiographic factors (cup abduction and anteversion), and surgical/implant factors (articulation size and head size).

## RESULTS

The mean follow-up time was 9.5 years (range, 5–13.9 years). The mean HHS values improved from a preoperative value of 46.5 (range, 14–69) to 94.4 (range, 80–99) at the final follow-up. The mean cup abduction was 31.5° (range, 25°–55°), and the mean cup anteversion was 19.5° (range, 12°–45.2°). One hip had intraoperative asymmetric seating (1/538, 0.18%) and was followed conservatively for 8 years without fracture of the liner (Fig. 2).

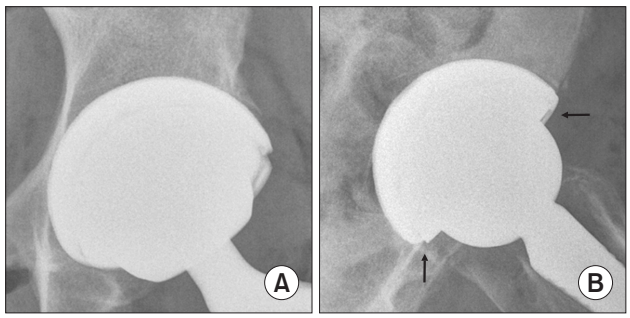


**Fig. 2.** (A) Anterior posterior radiography of the patient who was followed conservatively with symptomatic clicking after 6 months from index total hip arthroplasty. (B) Malseating of the delta ceramic liner (arrows) was detected on the immediate cross-table lateral view.

Eleven patients experienced noise generation (2%). It was defined as squeaking by 3 patients, cracking by 2 patients, and snap by 4 patients, and 2 patients were unable to define the sound. Four patients spontaneously complained of noise before the questionnaire. Two squeaking patients described during long distance walking and stair climbing and the other squeaking patient described noise during bending forward. All squeakers made noise loud enough to be heard around them and revision operation was recommended. Two crackers complained of the noise itself.

No femoral head or acetabular liner fractures were reported for the entire cohort. Three patients (3/514, 0.58%) reported reproducible squeaking (Table 2, Fig. 3). Multiple regression analysis for squeaking showed no significant differences in articulation size, sex, age, femoral stem offset (high offset vs. standard), femoral stem design, and anteversion; however, only inclination of the cup ($p < 0.001$) was significantly associated with noisy hips (Table 3). Noisy hips had increased inclination.

Four femoral components (0.77%) subsided. According to the Engh criteria for osteointegration, all stems had stable bony ingrowth, including the 2 subsided cases. The acetabular cups showed no indications of loosening. According to Brooker's classification, 5 hips had Grade I,

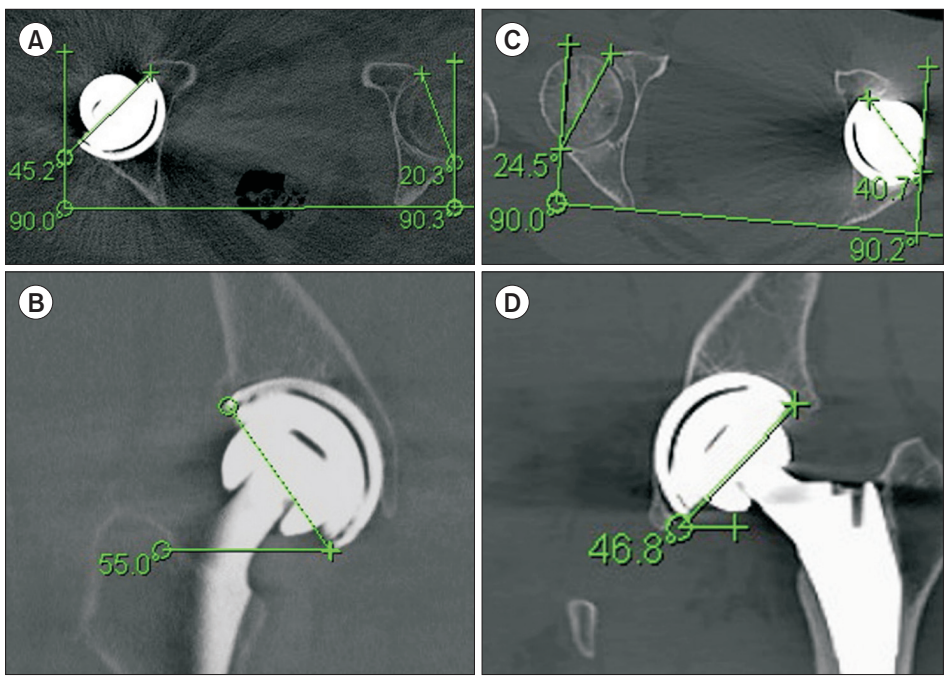


**Fig. 3.** High anteversion (A, C) and high inclination (B, D) angles were detected in patients who had sequential computed tomography analysis.

**Table 3.** Multiple Regression Analysis Showing That Only Inclination Had a Statistically Significant Association with Squeaking for Delta Liners

| Factor | Coefficient | Standard error | $r_{partial}$ | *t*-value | *p*-value |
|---|---|---|---|---|---|
| Acetabular inclination | 0.002 | 0.001 | 0.128 | 2.675 | 0.001* |
| Acetabular version | 0.008 | 0.001 | 0.471 | 9.338 | 0.059 |
| Femoral stem offset (standard-lateralized) | 0.005 | 0.008 | 0.296 | 0.612 | 0.570 |
| Femoral stem design (polar, anthology) | 0.001 | 0.006 | 0.010 | 0.206 | 0.826 |
| Age | 0.000 | 0.000 | 0.038 | 0.817 | 0.408 |
| Sex | 0.027 | 0.005 | 0.007 | –1.039 | 0.362 |
| Follow-up (yr) | –0.001 | 0.002 | –0.052 | –1.059 | 0.291 |
| Articulation size (28, 32, 36 mm) | 0.005 | 0.007 | 0.258 | 0.738 | 0.620 |

*$p < 0.05$.

and 6 hips had Grade II heterotopic ossification. No Grade III or IV heterotopic ossification was observed. Five patients underwent revision. One was treated with acetabular liner and femoral head revision due to recurrent dislocation after an average of 3.9 years. Two patients underwent a femoral component revision for periprosthetic fracture (at postoperative day 1 and after 3 months). One patient had a periprosthetic greater trochanteric fracture with dislocation, which was treated with open reduction and grip fixation 18 months after the index operation. One deep infection was treated with a 2-stage infection protocol.

Kaplan-Meier survivorship analysis showed a cup survival rate of 97.8% (95% CI, 95.2%–99.9%) after 10 years, using any revision as the endpoint. The worst-case scenario showed a 96.4% (95% CI, 94.2%–99.2%) survival rate for 10 years.

## DISCUSSION

This study demonstrates the excellent intraoperative seating, good-to-excellent survivorship, and clinical outcomes of the delta ceramic liner with a titanium taper locking band in combination with an 18° inner taper angle, multibearing cementless cup. A low ratio of noisy hips and no liner fractures were reported after an average of 6-year follow-up period.

The introduction of the delta ceramic liner to the market reduced the incidence of ceramic head fractures, but the incidence of liner fractures has not yet changed.[8] Reported delta liner fractures are more common (0.126%; median time to revision, 1.3 years) and tend to occur earlier than BIOLOX forte liner fractures (0.112%; median time to revision, 3.7 years).[6] Malseating may explain why the delta liner tends to require revision due to fracture in a shorter time period.

Central fracture and chip fracture of the peripheral rim are the 2 types of ceramic liner fractures.[9] Central-type fractures are more commonly associated with the malseating or asymmetrical seating of the liner.[9,10] Chipping-type fractures of the peripheral rim of the liner are associated with impingement between the inner edge of the ceramic liner and the stem neck.[7] The use of a multibearing metal shell with an inner taper angle of 10°, a thin metal shell combined with high impaction forces during impaction to the sclerotic acetabular bone bed, and a metal shell with a titanium-backed alumina ceramic liner are other reported risk factors for malseating and central ceramic fracture.[10]

Lee et al.[10,17] showed that the risk factors associated with malseating during insertion were significantly higher for the 10° inner taper metal shell than for the 18° metal shell, and the central-type delta liner fracture cases tended to be associated with the 10° inner taper metal shell. Lee et al.[18] also reported a prospective multicenter study, which showed the prevention of ceramic liner fractures when using an 18° inner taper angle and reduced neck geometry. No malseating or fractures were reported for 274 THAs using 32/3-mm delta CoC bearings without a titanium band.

Titanium and metal backed metal-ceramic liners have been reported to be a risk factor for incomplete seating and ceramic fracture.[19] However, the peripheral locking design of metal or titanium backed ceramic liner can vary across different manufacturers. The incidence of mal-

seating was reported at 7.2%–22.9% for Trident alumina ceramic liners, which feature visible protrusions of the titanium liner rim from the edge of the metal shell and have a 12° taper locking angle.[20,21] Despite the high malseating ratio, the long-term outcome of the trident alumina malseated liner was favorable without any fracture in a small sample size case series.[21] This type of metal shell was designed to prevent impingement between the stem neck and the ceramic liner, but may result in a disadvantage during liner placement, especially the inferomedial aspect area.[19] A recent long-term follow-up study reported that metal-backed Biolox delta ceramic liners, which have a 10° inner taper locking angle, showed lower malseating ratio (0.2%) without any head and liner fracture for 210 cases.[22] Only 1 (0.93%) misaligned R3 delta ceramic liner was reported due to soft-tissue interposition in the literature.[23] In our study, we observed 1 intraoperative asymmetric seated liner (0.19%) for cementless, multi-bearing cups with an 18° inner taper locking angle (Table 4). When R3 delta liner is totally seated in the shell, no visible overhang of the titanium band occurs in the absence of misalignment, which may be advantageous during the placement of the delta ceramic liner (Fig. 4).

Delta ceramic liners have a 0%–1.8% fracture rate, according to recently published data.[18] The most commonly reported type of delta ceramic liner fractures were central-type fractures.[24] However, Lim et al.[7] reported 2 cases of peripheral chipping fracture without malseating or trauma. Both fractures were defined in the posterior-inferior portion of the ceramic liner due to impingement of the stem neck and the inner edge of the ceramic liner. We did not observe any central or peripheral rim fractures of the delta ceramic liner after an average 9.5-year follow-up in 514 THA procedures. The titanium band might provide greater protection against chipped edges and tensile forces for ceramic inserts. The mechanical burst strength of these liners is significantly higher than that of traditional ceramic liners without titanium bands.[25]

Modular acetabular systems that contain a metal back liner can potentially be prone to backside corrosion and metallosis. The modular design of the R3 acetabular system was not appropriate for the Co-Cr metal liner and was recalled in 2012 by the manufacturer.[26] We did not observe any radiological and clinical sign of corrosion and

**Fig. 4.** Accurate alignment position of a delta ceramic liner with a titanium locking band into an 18° inner taper locking angle cementless hemispherical porous-coated acetabular shell. No visible overhang of the titanium metal part from the acetabular shell.

**Table 4.** Summary of Literature Related to Ceramic Fractures after Delta-on-Delta Bearing Surface Total Hip Arthroplasty

| Study | No. of patient hips | Mean follow-up (yr) | Inner taper angle (°) | Misalignment of ceramic liner (%) | Ceramic liner central fracture (%) | Ceramic liner peripheral fracture (%) | Ceramic head fracture (%) | Squeaking (%) | Implant survival (KM%) |
|---|---|---|---|---|---|---|---|---|---|
| Baek et al.[27] | 94 | 5.3 | 18 | 1 / 94 (1.09) | 0 | 0 | 0 | 3.2 | 96.8 |
| Lee et al.[17] | 286 | 5.5 | 10 | 1 / 286 (0.34) | 0 | 0.3 | 0 | 11.9 | 99.4 |
| Hamilton et al.[24] | 177 | 5.3 | 10 | 3 / 177 (1.69) | 1.8 | 0 | 0 | 7.5 | 96.9 |
| Salo et al.[28] | 336 | 2.1 | 10 | NM | 0 | 0 | 0 | 17 | 99.1 |
| Lee et al.[18] | 274 | 6.0 | 18 | 0 | 0 | 0 | 0 | 3.2 | 99.6 |
| Lim et al.[7] | 749 | 6.5 | 18 | 0 | 0 | 0.3 | 0 | 6.4 | 98.6 |
| Wagner et al.[22] | 210 | 10.2 | 10 | 0.2 | 0 | 0 | 0 | 0.2 | 97.0 |
| Assaf et al.[23] | 107 | 7 | 18 | 1 / 107 (0.93) | NM | NM | NM | NM | 97.69 |
| This study | 514 | 9.5 | 18 | 1 / 515 (0.19) | 0 | 0 | 0 | 0.68 | 97.8 / 96.4* |

KM: Kaplan-Meier analysis, NM: not mentioned.
*Worst-case scenario.

adverse tissue reaction between the titanium taper locking band of the delta ceramic liner and the R3 acetabular cup at midterm follow-up.

Another ceramic liner-related complication is noisy hips, which are associated with ceramic liner anterior-superior edge loading and acetabular cup abduction and anteversion.[29] The reported prevalence of squeaking after delta ceramic THA ranges from 0% to 28%. Lee et al.[17] found no differences between the noisy and non-noisy groups in acetabular cup abduction, but the mean anteversion of the acetabular component was higher for the noisy group. Esposito et al.[30] analyzed 54 aluminum CoC bearings from THA based on gravimetric and roundness measurements. Squeaking hips showed anterior-superior edge wear and were associated with higher anteversion (> 22°). Although the combination of a high acetabular component inclination (55°) and high anteversion (> 25°) resulted in increased wear and the increased incidence of anterior-superior edge loading, high acetabular inclination alone might not produce anterior-superior edge loading in cases of low anteversion.[30] The causes of articular noise are multifactorial and can be associated with patients' demographics (high BMI, young age, or activity level) or surgical factors (cup orientation, stem size and offset, or taper design).[31] We had 3 noisy hips (0.68%), all of which were reported as reproducible squeaking. The squeaking onset occurred between 32 to 72 months after the index THAs. All patients had higher anteversion, ranging from 33.4° to 45.2°, with inclination ranging from 42° to 55° (Table 2).

This study has several limitations. As this study was performed as a retrospective study, no control group was used, and the patients were not randomized, which could have biased the results. Moreover, a considerable number of patients (514 hips) had complete radiographic and clinical findings that permitted the evaluation of midterm performance. Second, all surgical operations were performed by the high-volume senior surgeon, which might have affected the cup orientations. Third, this study has a relatively short follow-up, and the prevalence of self-reported articular noise was low. However, after a mean 10-year follow-up period, articular noise has been reported for 28% of delta CoC articulations, without impacting quality of life.[32] Fourth, we did not use a standard stem type, which may have affected the number of noisy hips. The measurement of acetabular anteversion with the classical method with cross-table lateral radiographs is another limitation of the study. But If the qualified lateral radiograph was selected, anteversion measured using the method of Woo and Morrey would be relatively reliable. The use of different stem types could affect the squeaking occurrence.

Ceramic liner fractures and malseating are rare with or without the use of a titanium locking band. However, using a delta ceramic liner with a titanium locking band with an 18° inner taper angle multi-bearing cementless cup showed minimal malseating risk (0.18%) and we did not observe any liner fractures or head fractures during an average 9.5-year follow-up period for 514 THAs using delta CoC bearings.

## CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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