CLINICAL SCIENCE

POLYETHYLENE WEAR AND PAPROSKY MAP: AGE DRIVEN ACETABULAR BONE LOSS IN CEMENTED AND CEMENTLESS THA REVISIONS

Darko Talevski[1], Jasminka Nancheva[2], Jasmin Ciriviri[1], Nenad Atanasov[2], Zoran Nestorovski[1], Tode Vraniskoski[1], Nenad Petkov[1], Aleksandar Karevski[1], Zorica Vangelovska[1], Dusko Ciriviri[1], Aleksandra Jovanova[1]

[1] *City General Hospital "8th September", Skopje, North Macedonia*

[2] *University Clinic for Traumatology, Orthopedic Disease, Anesthesiology, Reanimation and Intensive Care Medicine and Emergency Department, Clinical Center "Mother Theresa", Faculty of Medicine, Ss. Cyril and Methodius University in Skopje, North Macedonia*

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***Correspondence:** Darko Talevski, City General Hospital "8th September", Skopje, North Macedonia

Email: darko_talevski@yahoo.com

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Abstract

Objective: To evaluate acetabular bone loss patterns, classified by the Paprosky system, in cemented and cementless acetabular components revised for polyethylene wear–related aseptic loosening, and to determine whether age, time to revision, and body mass index (BMI) predict greater defect severity. Methods: A retrospective cohort study was conducted involving 60 acetabular revision total hip arthroplasties, divided into cemented (n=30) and cementless (n=30) fixation groups. All revisions were undertaken for aseptic loosening attributed to polyethylene wear, with primary cups implanted within the Lewinnek "safe zone". Cases with developmental dysplasia, inflammatory arthropathy, or prior infection were excluded. Baseline variables were age, sex, BMI, and time to revision. Acetabular bone loss was graded radiographically using the Paprosky classification (I, IIA, IIB, IIC, IIIA, IIIB). Group differences in Paprosky subtype distribution were tested with chi-square analysis. Ordered logistic regression was employed to examine predictors of increasing Paprosky rank, and multivariable logistic regression to evaluate predictors of severe defects (Paprosky III vs. I–II), with BMI as the primary exposure and adjustment for fixation type, age, sex, and time to revision. Results: The Paprosky subtype distribution did not differ significantly between cemented and cementless cups (p=0.26). Higher age at revision was independently associated with more severe Paprosky categories (OR 1.08 per year, p=0.036), whereas fixation type showed only a non-significant trend toward higher severity for cementless components. BMI was not associated with severe acetabular defects, and cementless fixation showed a non-significant trend toward Paprosky III defects. Conclusions: In patients with polyethylene wear–related aseptic loosening, acetabular defect severity according to Paprosky classification appears more closely related to patient age - and, by implication, cumulative time in situ - than to fixation concept or BMI. Cemented and cementless acetabular components showed similar Paprosky defect distributions, and BMI was not an independent predictor of severe bone loss. These findings underscore the central role of long-term wear and osteolysis in acetabular bone loss and support development of models that integrate time-dependent wear exposure, key implant characteristics, and advanced imaging-based assessment to guide timing and strategy of revision total hip arthroplasty.

КЛИНИЧКИ ИСТРАЖУВАЊА

ПОЛИЕТИЛЕНСКО АБЕЊЕ И PAPROSKY КЛАСИФИКАЦИОНЕН СИСТЕМ: ВРЕМЕНСКИ-ЗАВИСНО АЦЕТАБУЛАРНО ГУБЕЊЕ НА КОСКЕНОТО ТКИВО УВИДЕНО КАЈ РЕВИЗИИ НА ЦЕМЕНТНА И БЕЗЦЕМЕНТНА ТОТАЛНА ЕНДОПРОТЕЗА НА КОЛК

Дарко Талевски[1], Јасминка Нанчева[2], Јасмин Циривири[1], Ненад Атанасов[2], Зоран Несторовски[1], Тоде Вранишкоски[1], Ненад Петков[1], Александар Каревски[1], Зорица Вангеловска[1], Душко Циривири[1], Александра Јованова[1]

[1] *Градска општа болница „8-ми Септември" – Скопје, Северна Македонија*

[2] *Универзитетска клиника за трауматологија, ортопедија, анестезија, реанимација, интензивно лекување и ургентен центар, Клинички центар „Мајка Тереза", Скопје, Северна Македонија*

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Клучни зборови: артропластика, протеза на колк, коскена ресорпција, разлабавување на протеза

***Кореспонденција:** Дарко Талевски, Градска општа болница „8-ми Септември" – Скопје, Северна Македонија

Email: darko_talevski@yahoo.com

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Печатарски права: ©2026 Дарко Талевски, Јасминка Нанчева, Јасмин Циривири, Ненад Атанасов, Зоран Несторовски, Тоде Вранишкоски, Ненад Петков, Александар Каревски, Зорица Вангеловска, Душко Циривири, Александра Јованова. Оваа статија е со отворен пристап дистрибуирана под условите на нелокализирана лиценца, која овозможува неограничена употреба, дистрибуција и репродукција на било кој медиум, доколку се цитираа торигиналниот(ите) автор(и) и изворот.

Конкурентски интереси: Авторот изјавува дека нема конкурентски интереси.

Извадок

Цел: Да се процени моделот на ацетабуларно губење на коската класифицирано според Paprosky кај цементни и безцементни ацетабуларни компоненти ревидирани поради асептично олабавување поврзано со полиетиленско абење, и да се утврди дали возраста, времето до ревизија и индексот на телесна маса (ИТМ) предвидуваат поголема тежина на дефектот. Методи: Спроведовме ретроспективна кохортна студија на 60 ревизии на тотална ендопротеза на колк, поделени во цементна (n=30) и безцементна група (n=30). Сите ревизии беа поради асептично олабавување припишано на полиетиленско абење, со примарни чашки вградени во „безбедната зона" според Lewinnek. Беа исклучени случаите со развојна дисплазија, воспалителна артропатија или претходна инфекција. Основните варијабли беа: возраст, пол, BMI и време до ревизија. Ацетабуларното губење на коската беше радиографски класифицирано според Paprosky (I, IIA, IIB, IIC, IIIA, IIIB). Разликите во дистрибуцијата на поттиповите помеѓу групите беа тестирани со хи-квадрат тест. Со ординална логистичка регресија се испитуваа предикторите на зголемена Paprosky класификациона тежина, а со мултиваријантната логистичка регресија се анализираа предикторите за сериозни ацетабуларнидефекти (Paprosky III vs. I–II), со BMI како примарна изложеност и прилагодување за фиксација, возраст, пол и време до ревизија. Резултати: Немаше значајна разлика во дистрибуцијата на Paprosky поттиповите помеѓу цементните и безцементните чашки (p=0,26). Поголемата возраст при ревизија беше независно поврзана со повисоки Paprosky категории (OR 1,08 по година; p=0,036), додека типот на фиксација покажа само несигнификантен тренд кон поголема тежина кај безцементните компоненти. BMI не беше поврзан со сериозни ацетабуларни дефекти, а безцементната фиксација покажа несигнификантен тренд кон Paprosky III дефекти. Заклучоци: Кај пациенти кај кои постои асептично олабавување поврзано со полиетиленско абење, екстензивноста на ацетабуларниот дефект според Paprosky е повеќе поврзана со возраста и кумулативното време in situ отколку со типот на фиксација или BMI. Цементните и безцементните ацетабуларни компоненти покажаа слична распределба на Paprosky дефектите, а BMI не беше независен предиктор за опсежно губење на коската. Овие наоди ја нагласуваат примарната улога на долготрајното абење и остеолизата и укажуваат на потреба од предиктивни модели што ќе интегрираат временски зависна изложеност на абење во зависност од времето, карактеристики на имплантот и напредна дескриптивна проценка заснована на радиолошки иследувања за оптимално планирање на ревизиска тотална ендопротеза на колк.

Introduction

Total hip arthroplasty (THA) is widely regarded as one of the most effective surgical interventions for relieving pain, restoring function, and improving quality of life in patients with degenerative and post-traumatic pathology of the hip joint. Its utilization has risen steadily across the globe, in parallel with population aging and expanding indications in younger, more active individuals[1]. Aseptic loosening of the acetabular component remains the most common indication for revision THA and represents a major clinical and economic burden[2]. The extent and pattern of acetabular bone loss at the time of revision surgery strongly influence reconstructive complexity, implant choice, and the risk of subsequent re-revision, highlighting the importance of understanding how acetabular defects develop and progress[3,4].

The dominant driver of late aseptic loosening is periprosthetic osteolysis induced by particulate wear, most frequently from polyethylene liners[5,6]. Wear particles disseminate throughout the effective joint space and elicit a chronic foreign-body reaction in which macrophages phagocytose debris and release pro-inflammatory mediators that stimulate osteoclast-mediated bone resorption. This process leads to progressive periacetabular bone loss and the formation of a fibrous membrane at the bone–implant interface, ultimately compromising mechanical stability and resulting in loosening[5,7]. Historically, such changes were attributed to "cement disease," but long-term studies have shown that extensive osteolysis occurs around both cemented and cementless components, indicating that polyethylene wear and expansion of the effective joint space, rather than the presence of cement per se, are the principal etiologic factors[8,9]. In cemented constructs, debris can propagate along the cement–bone and cement–implant interfaces, whereas in cementless designs, particles may migrate along the porous surface, screw holes, and modular junctions, but in both settings' patient-related factors such as activity level and body mass index, and implant-related factors such as design and positioning, modulate wear and osteolysis patterns[10,1]. Consequently, the severity of acetabular bone loss at revision has profound implications for postoperative function, complication risk, and the likelihood of further revision[3,4].

Accurate characterization of acetabular bone loss is therefore essential for preoperative planning, selection of reconstruction strategy, and prognostic assessment in revision THA[11,12]. The Paprosky classification is the most widely used system for grading acetabular defects and is based on radiographic evaluation of hip center migration, integrity of the anterior and posterior columns and acetabular walls, and the presence of cavitary or segmental defects[13–15]. By stratifying bone loss into ordered categories from minimal to massive deficiency, it provides a common language for describing defects, comparing cohorts, and guiding the choice between hemispherical cups, augments, cages, and custom implants 16. However, despite its widespread adoption, the Paprosky system shows only fair to moderate interobserver agreement in many studies, reflecting the difficulty of translating complex three-dimensional bone loss into two-dimensional radiographic

categories and the frequent obscuration of key landmarks by the radiopaque cup[17–19]. Standardized training and structured radiographic analysis can improve reliability, but there remains a need to better link radiographic grading with actual defect morphology and clinical risk 15,20. Moreover, conventional radiographic classifications may underestimate the true complexity of periprosthetic bone loss, motivating the exploration of advanced techniques such as statistical shape modeling to enhance quantitative assessment and reproducibility[21].

Within this context, relatively few studies have specifically examined how polyethylene wear–related osteolysis translates into distinct Paprosky defect patterns in cemented versus cementless acetabular components[16]. By comparing the distribution and severity of Paprosky types between fixation modalities and correlating these patterns with clinical parameters such as implant survival time and body mass index, this investigation aims to identify characteristic modes of bone loss and potential predictors of more advanced defects[22-24,25].

Materials and Methods

Study design and cohort

This was a retrospective cohort analysis of 60 acetabular revision total hip arthroplasty procedures. Cases were divided into two fixation groups (cemented vs. cementless; 30 cases per group). In all cases, the acetabular liners were second-generation ultra-high molecular weight polyethylene (UHMWPE) articulating with a 28-mm cobalt–chromium (CoCr) femoral head.The indication for revision was constant across the cohort: aseptic loosening of the acetabular component attributed to polyethylene wear. Inclusion criteria were: (1) revision of a primary total hip arthroplasty for aseptic loosening of the acetabular component attributed to polyethylene wear, and (2) primary acetabular components implanted within the Lewinnek “safe zone” for cup orientation on standard radiographs[26]. We excluded patients with developmental dysplasia of the hip, inflammatory or autoimmune hip arthritis, and any history of periprosthetic joint infection in order to avoid the confounding effects of abnormal native acetabular morphology, systemic inflammatory disease, or infection-related bone loss on defect patterns.

Variables

Baseline variables included age at revision (years), sex, body mass index (BMI; kg/m^2), year of implantation, year of revision, and time to revision (years, derived as year of revision minus year of implantation). The primary outcome was acetabular defect severity categorized by the Paprosky classification (I, IIA, IIB, IIC, IIIA, IIIB)[25]. For ordinal regression, Paprosky categories were coded into an ordered rank from 1 (I) to 6 (IIIB). For binary regression, severe defects were defined as Paprosky III (IIIA/IIIB) and compared against non-severe defects (I/IIA/IIB/IIC).

Statistical analysis

Statistical analyses were performed using IBM SPSS Statistics (version 30.0; IBM Corp., Armonk, NY, USA). Continuous variables are summarized as mean (SD) and median [IQR] as appropriate. Between-group com-

parisons (cemented vs. cementless) were performed using Welch's t-test for mean differences and Mann–Whitney U tests for nonparametric comparisons. Categorical comparisons were analyzed using Fisher's exact test. Differences in Paprosky subtype distribution by fixation were evaluated using the chi-square test. Association between predictors and increasing Paprosky severity was evaluated using ordered logistic regression (proportional odds model), reporting odds ratios (OR) with 95% confidence intervals (CI). Association between predictors and severe defects (Paprosky III) was evaluated using multivariable logistic regression with BMI as the primary exposure. Models report OR with 95% CI; two-sided $p<0.05$ was considered statistically significant.

Results and Interpretation

The results of this study are presented as baseline comparisons and time-to-event analyses stratified by fixation type, followed by adjusted models evaluating associations with defect severity. Collectively, these findings summarize the observed group differences and the independent effects after accounting for potential confounders.

Table 1 summarizes baseline characteristics by fixation type; Table 1b reports p values for between-group comparisons. In this cohort, patients in the cemented group were older at revision and had longer time to revision. BMI differed between groups statistically.

Ordered logistic regression results are shown in Table 3. Age at revision was associated with higher

Table 1: Baseline characteristics by fixation type

Variable	Group	Value
n	cemented	30
Age, mean (SD)	cemented	76.4
BMI, mean (SD)	cemented	25.4
n	cementless	30
Age, mean (SD)	cementless	64.9
BMI, mean (SD)	cementless	27.7

Table 1b: P values for group comparisons

Variable	Test	p value
age	t-test	0.0
body mass index	t-test	0.0075
time to revision	t-test	0.0
severe defect (Paprosky III)	chi-square	0.4216

Table 2 and Figure 1 describe Paprosky subtype distribution by fixation type. The overall distribution did not differ significantly between groups (Chi-square test: $\chi^2(5)=6.47$, $p=0.2627$).

Table 2: Paprosky subtype distribution by fixation type

Paprosky subtypes	cemented	cementless
1	3	1
2A	3	4
2B	5	8
2C	9	4
3A	6	6
3B	2	7

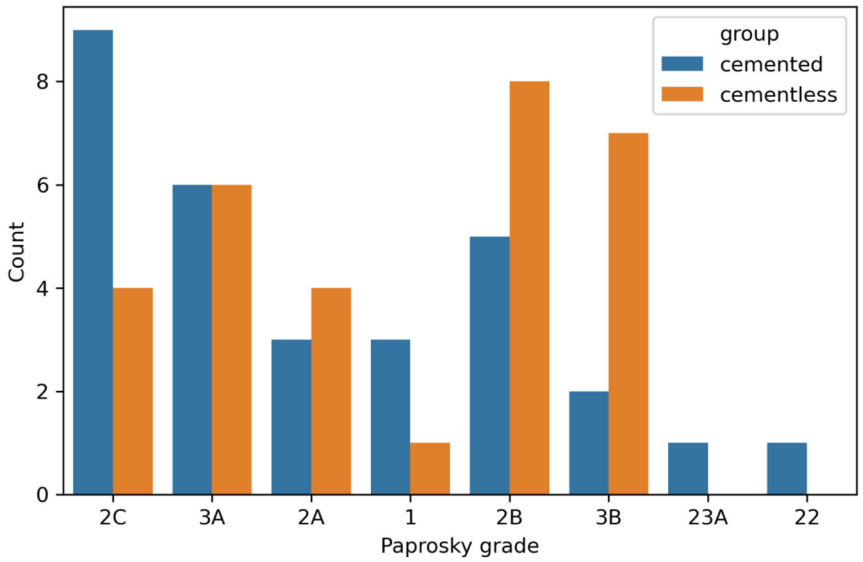


Figure 1: Paprosky subtype distribution by fixation type

Paprosky severity (OR 1.08, 95% CI 1.01–1.16, p=0.0356).

Fixation type showed a directional trend: cementless (vs. cemented) was associated with higher severity, but this did not reach statistical significance (OR 3.91, 95% CI 0.79–19.5, p=0.0958). The wide CI suggests limited power and/or substantial variability.

Multivariable logistic regression for severe defects (Paprosky III vs. I–II) is shown in Table 4. BMI was

Table 3: Ordered logistic regression for higher Paprosky rank (OR with 95% CI)

	coef	OR	CI low	CI high	p
Group	1.3647	3.9144	0.758	19.4996	0.0958
BMI	0.013	1.0131	0.8514	1.2054	0.8836
Time to revision years	0.0027	1.0027	0.84	1.197	0.976
Age/revision	0.0772	1.0803	1.0052	1.1609	0.0356
Female	0.4687	1.598	0.5041	5.0656	0.4259

not associated with severe defects (OR 1.03, 95% CI 0.84–1.26, p=0.7813). Fixation type showed a non-significant trend toward severe defects for cementless vs. cemented group (OR 4.59, 95% CI 0.73–28.92, p=0.1045). Table 4b provides the unadjusted BMI-only model for comparison.

Figure 3 visualizes time to revision by fixation type. The cemented group demonstrated a longer

Table 4: Logistic regression for severe defects (Paprosky III vs. I–II).

	coef	OR	CI low	CI high	p
Const	-8.3797	0.0002	0.0	4.0873	0.0933
BMI	0.029	1.0295	0.8386	1.2638	0.7813
Group	1.5244	4.5922	0.7291	28.924	0.1045
Time to revision years	-0.0132	0.9869	0.8043	1.2111	0.8997
Age revision	0.0856	1.0894	0.9873	1.2021	0.0881
Female	0.5393	1.7149	0.4357	6.7491	0.4404

Table 4b: Unadjusted logistic regression for severe defects with BMI only

	coef	OR	CI low	CI high	p
Const	-1.8086	0.139	0.0026	10.1831	0.3907
BMI	0.0447	1.0457	0.897	1.219	0.5681

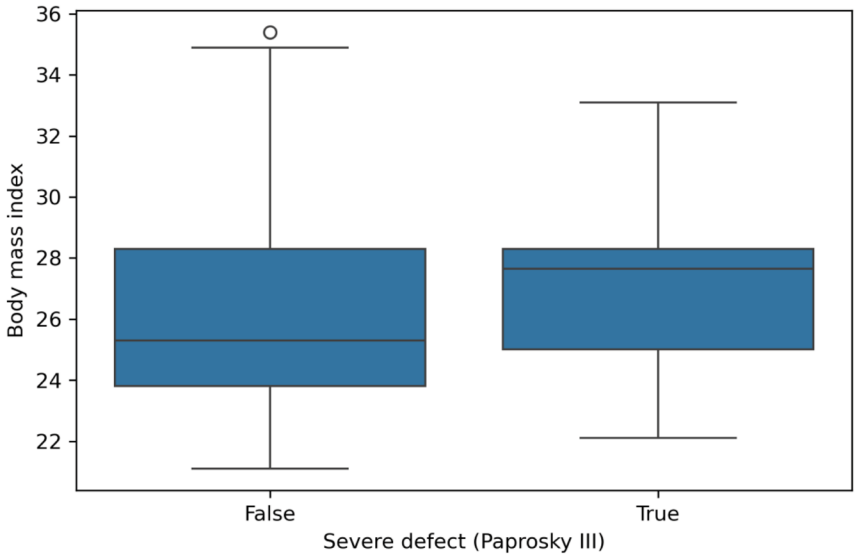


Figure 2: Body mass index by defect severity (Paprosky III vs I–II)

time to revision, consistent with the baseline comparisons. Because the groups differed at baseline, a simple unadjusted comparison of defect severity could be misleading; therefore, we used adjusted models.

Discussion

Age at revision emerged as the only clinical factor independently asso-

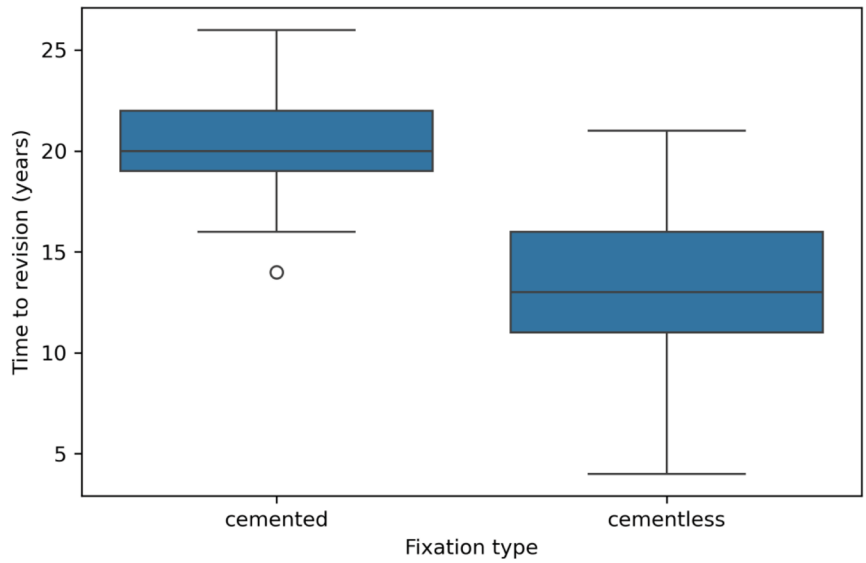


Figure 3: Time to revision by fixation type

ciated with higher Paprosky defect severity, pointing to a strong influence of cumulative time in situ on acetabular bone loss. In contrast, fixation concept (cemented vs cementless) did not materially alter the distribution of Paprosky subtypes, and BMI showed no association with severe Paprosky III defects. Taken together, these results suggest that polyethylene wear over time, rather than fixation type or patient body habitus, is the primary driver of advanced acetabular defects in this revision cohort.

This study examined how acetabular bone loss, graded by the Paprosky classification, presents in cemented and cementless acetabular components revised for polyethylene wear–related aseptic loosening, and whether clinical factors such as age, time to revision, and BMI predict more severe defects. Overall, fixation type did not significantly change the distribution of Paprosky subtypes, and BMI was not associated with severe Paprosky III defects, whereas age at revision emerged as an independent predictor of higher defect severity. These findings support the central role of polyethylene wear and time in situ as the main drivers of osteolysis and bone loss and highlight the limitations of relying on simple clinical variables or fixation concept alone to anticipate complex acetabular defects[2,27,28].

The absence of a statistically significant difference in Paprosky distribution between cemented and cementless cups suggests that, under the common pathway of polyethylene wear, both fixation concepts are vulnerable to similar patterns of acetabular bone loss. This observation is consistent with long-term series showing that extensive osteolysis and large cavitary or segmental defects occur around both cemented and cementless implants when wear is high and implants remain in situ for prolonged periods 29. In this context, the non-significant trend toward more severe

defects in cementless components, with wide confidence intervals in our regression models, should be interpreted as hypothesis-generating rather than definitive and may reflect differences in implant longevity, particle migration pathways, or unmeasured design features. Our data therefore do not support fixation type as a dominant independent determinant of Paprosky class but rather emphasize the need to view fixation as one element within a more complex construct-level analysis[2].

By contrast, the finding that older age at revision correlates with higher Paprosky severity is consistent with the concept that cumulative exposure to wear and osteolytic activity over time drives progressive bone depletion. Previous work has demonstrated strong associations between polyethylene wear rate, implant time in situ, and the development of major acetabular defects requiring complex reconstruction. In our cohort, cemented cases showed longer time-to-revision but not systematically more severe defects, suggesting that fixation mode and implant design may modify how cumulative wear translates into structural loss. This nuance supports a more sophisticated view: time and wear are necessary but not sufficient, and the specific construct (cup design, liner thickness, articulation, and possibly stem mechanics) modulates the final defect pattern[1,2,30].

The lack of association between BMI and severe Paprosky defects in adjusted models is also clinically relevant. Although obesity has often been assumed to increase wear and complications, several contemporary studies report that BMI is not a strong independent predictor of polyethylene wear or liner/head migration when implant placement and bearing characteristics are optimized[27,28]. Our results are consistent with this evidence and suggest that BMI, taken in isolation, should not be used as a surrogate marker for severe acetabular bone loss in polyethylene wear–driven revisions. Rather, BMI likely interacts with technical factors such as visualization, positioning, and activity patterns, and should be incorporated into broader, multifactorial models rather than treated as a standalone risk factor.

An important implication of our work is the central role and the limitations of the Paprosky classification in current practice. Using Paprosky types as the primary outcome reflects its status as the most widely adopted framework for describing acetabular bone loss and guiding reconstructive strategy in revision THA. However, variability in interobserver agreement and discrepancies between preoperative radiographic grading and intraoperative findings have been repeatedly reported, especially for complex three-dimensional defects and posterior/ischial bone loss obscured by the cup[12,16,19,31]. This classification noise may partially attenuate observable associations with clinical predictors, while the robust association with age suggests that only larger effects are detect-

able through this variability. At the same time, our data demonstrate that even with these limitations, meaningful patterns—such as the effect of age and time in situ—are identifiable, supporting the continued use of Paprosky while underscoring the need for improved imaging and classification tools.

From a broader perspective, our research is important because it directly addresses two pressing clinical needs: earlier identification of patients at risk of catastrophic acetabular bone loss and more individualized planning of revision strategies. Our findings show that simple stratification by fixation type or BMI is insufficient and point towards more nuanced, model-based approaches that integrate time in situ and generation of wear (including liner material and thickness, head size, and articulation), precise component positioning and biomechanics, and patient factors beyond BMI alone. This naturally leads to the concept of predictive models for acetabular defects in both cemented and cementless implants. Existing data on wear thresholds and their relationship to severe bone loss suggest that longitudinal measurements of wear and component position could be combined with patient and implant characteristics to estimate the probability of progressing to Paprosky III defects[21,30]. Our study contributes to this agenda by clarifying which readily available clinical parameters (age and time to revision) carry more predictive value and which (BMI, fixation type alone) are less informative, thereby helping to define the variable set that future models should prioritize.

A further strength of our concept is the explicit recognition that the femoral stem and its biomechanical behaviour may influence acetabular wear and osteolysis, even though our current dataset is acetabular-focused. Stem geometry, offset options, neck-shaft angle, stiffness, and fixation (cemented vs cementless) alter joint reaction forces and load transfer, which in turn affect polyethylene contact mechanics at the acetabular liner[32,33]. Certain stem designs may predispose to higher edge loading or altered pelvic tilt and thus to characteristic patterns of acetabular wear and defect formation. By framing future research around the total construct rather than the cup in isolation, we provide a rationale for studies that stratify Paprosky patterns by stem design and employ finite-element or gait-based models to mechanistically link femoral biomechanics to acetabular osteolysis. Finally, our study underscores the need for continued basic and translational research on osteolytic lesions themselves: how particles are generated and transported within the effective joint space, how local bone–immune interactions evolve over time, and why some patients develop extensive silent lesions while others do not. As advanced CT-based 3D reconstruction and statistical shape modeling become more widely available, integrating these tools with Paprosky grading, clinical variables, and implant de-

sign offers a promising path toward more accurate prediction, earlier intervention, and more bone-preserving revision strategies[20,21,31]. In this sense, our current findings are not an endpoint but a foundation: they identify key clinical signals, expose the limits of conventional predictors, and clearly map the trajectory for future research aimed at understanding and ultimately preventing severe acetabular bone loss in total hip arthroplasty.

This study has several limitations. It is a retrospective, single center analysis with a relatively small sample size, which limits generalizability. Acetabular bone loss was classified using standard radiographs and the Paprosky system, which may not fully capture three dimensional defect morphology or avoid interobserver variability. We also lacked direct measurements of polyethylene wear and detailed data on implant design and patient activity, so residual confounding cannot be excluded. This may also have introduced selection and information bias, meaning that the observed associations between age, fixation type, and defect severity should be interpreted with appropriate caution.

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