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RADIOLOGICAL CHARACTERISTICS OF OSTEOLYSIS IN CEMENTED VS. CEMENTLESS TOTAL HIP ARTHROPLASTY: A COMPARATIVE STUDY OF OSTEOLYTIC PATTERNS

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Abstract

Background: Even though THA is a highly effective surgical procedure, its long-term success is frequently compromised by periprosthetic osteolysis and subsequent aseptic loosening of the implant. This study aims to: 1) compare the radiological features of osteolysis in cemented versus cementless THA, 2) locate the osteolytic zones using standard X-rays and 3) calculate the precise volume of these lesions using advanced CT scans.

Methods: This is a comparative retrospective analysis of prospectively collected imaging data with primary concern on providing important information about the radiological patterns of osteolysis using objective and quantitative ways to measure the severity and the progression related to the fixation method (cemented vs. cementless). Osteolytic lesions were identified and quantified according to the Gruen zones on the femoral side and the DeLee and Charnley classification on the acetabular side, with volumetric CT-based measurements used to characterize patterns of bone degradation.

Results: In this comparative analysis of 60 revised total hip arthroplasties, we found that cementless implants exhibited a distinctly more aggressive osteolytic phenotype than cemented implants, despite being in situ for markedly shorter durations. Cemented THA were revised later (median 20 vs 13 years) and predominantly in older patients, yet demonstrated substantially lower volumetric osteolysis across both the femoral and acetabular sides. Cementless hips showed nearly threefold greater total osteolytic burden (median 72.8 vs 23.9 cm³), with disproportionately high involvement of proximal femoral Gruen zones (1–3) and the superolateral acetabular zone (DeLee–Charnley zone 1).

Conversely, cemented constructs exhibited relatively greater osteolytic involvement in distal femoral zones, consistent with endosteal cement–bone interface remodeling. Scatterplot analyses reinforced these patterns: cementless components accumulated significantly larger osteolytic volumes earlier in their lifespan, indicating a fundamentally different—and more rapid—biologic response to wear and fixation type.

Conclusion: These findings suggest that fixation method exerts a powerful influence on the magnitude, tempo, and topographic distribution of osteolysis, with important implications for surveillance strategies, implant selection, and revision planning.

Keywords: Total hip arthroplasty; Cemented hip prosthesis, Cementless hip prosthesis, Cementless hip prosthesis, periprosthetic osteolysis, polyethylene wear, CT, volumetric imaging, 3D slicer.

Introduction

Total hip arthroplasty is a successful orthopedic procedure, but its long-term effectiveness is often limited by periprosthetic osteolysis. This condition, also known as "particle disease," involves bone loss around the implant due to the body's reaction to wear particles, mainly from polyethylene components. [1] Osteolysis can occur with both cemented and cementless implants, leading to aseptic loosening and the need for revision surgery [2].

The leading complication of total joint replacement is periprosthetic osteolysis, which often results in aseptic loosening of the implant, leading to revision surgery [3]. Extracellular matrix degradation and connective tissue remodeling around implants have been considered as major biological events in the periprosthetic loosening process.

Critical mediators of wear particle-induced inflammatory osteolysis released by periprosthetic synovial cells (mainly macrophages) are inflammatory cytokines, chemokines, and proteolytic enzymes, mainly matrix metalloproteinases (MMPs) [4].

Periprosthetic osteolysis, defined as progressive bone loss around an orthopedic implant, is a primary factor contributing to late aseptic loosening and necessitates revision surgery [5]. This condition is predominantly triggered by the host's inflammatory response to wear particles generated at the implant interfaces, particularly from polyethylene components [5]. Although osteolysis can occur in both cemented and cementless total hip arthroplasty, its prevalence and characteristics may differ based on the fixation method and the magnitude of polyethylene wear [5].

Cemented prostheses typically fail due to stress shielding and the reaction to debris causing an increase in the space at the bone-cement interface [6]. Conversely, cementless prostheses are prone to bone resorption due to factors such as micromotion and the direct interaction of wear debris with the bone-implant interface, leading to different patterns of osteolytic lesion formation [7].

By analyzing the distribution and volume of osteolytic lesions, this research seeks to understand if there are differences in how wear particles spread and how the body responds in cemented versus cementless implants. Early detection of osteolysis is crucial because its progression can be subtle, making clinical diagnosis of aseptic loosening difficult [8]. As wear particles accumulate, bone resorption becomes a self-sustaining process, creating larger spaces that worsen bone loss.

This research will provide important information about the radiological patterns of osteolysis, which can help develop better monitoring strategies and treatments to extend implant life and improve patient outcomes. Specifically, by identifying variations in lesion presentation between cemented and cementless constructs, this study will improve clinical strategies for implant longevity [9].

We will provide objective, quantitative ways to measure the severity and progression of osteolysis, moving beyond subjective radiographic interpretations [10]. This will enable a more nuanced understanding of the disease's pathogenesis, informing targeted interventions to mitigate osteolysis and prevent implant failure [11].

This comparative analysis, specifically examining osteolytic zones on the femur according to Gruen zones and on the acetabular side using DeLee and Charnley classifications, coupled with volumetric analysis of CT-based lesions, will elucidate distinct patterns of bone degradation related to the fixation method.

Understanding these differences is pivotal for optimizing surgical approaches and developing more effective strategies for long-term implant survival, especially given the rising life expectancy of patients and subsequent increased exposure to long-term problems such as osteolysis and periprosthetic fractures [12].

This review will synthesize current knowledge regarding the radiological presentation of osteolysis, encompassing both standard radiographic methodologies and advanced volumetric imaging techniques. It will also explore the biomechanical implications of implant fixation in osteoporotic bone, as bone quality significantly influences the progression of periprosthetic bone loss and implant stability [13].

Furthermore, the interplay between osteolysis and periprosthetic fractures underscores the clinical challenge, as the reduction in local bone consistency often complicates osteosynthetic procedures in elderly patients with compromised bone stock [14].

This study aims to compare the radiological features of osteolysis in cemented versus cementless THA. We will focus on two aspects: the location of osteolytic zones using standard X-rays, and the precise volume of these lesions using advanced CT scans with 3D Slicer software.

Materials and Methods

Study Design and Patient Selection

We made a single-center comparative study following approval by the institutional board, of osteolytic zones on standard X-rays, adhering to Gruen zones for femoral and DeLee and Charnley zones for acetabular analysis. Additionally, volumetric analysis of osteolytic lesions identified on CT scans was performed using 3D Slicer, providing a quantitative assessment of lesion size and distribution, which is a significant advancement over two-dimensional measurements.

The exclusion criteria included differentiating patients with comorbidities and significant confounding factors that could independently contribute to bone loss such as periprosthetic joint infection, autoimmune diseases, and patients with chronic corticosteroid therapy.

Implant Fixation Groups

Ultimately, in our study we included 60 patients with polyethylene wear-induced osteolysis, meticulously selected to ensure a representative cohort for comparative analysis between cemented and cementless total hip arthroplasty and were categorized into two groups.

The endoprostheses analyzed in the cementless group were from two different manufacturers while the cemented group was from a single manufacturer. The articulating head size was 28 mm in both groups, and the polyethylene of the acetabular liner was ultra-high molecular weight polyethylene (UHMWPE), second generation. The baseline characteristics of enrolled patients are shown in Table 1.

The demographic data, including age, gender, body mass index and duration since primary arthroplasty, were systematically collected for each patient to identify potential distorting variables or demographic-specific patterns of osteolysis.

Radiographic Assessment of Osteolysis and Data Analyses

Radiographic images were systematically reviewed by two independent, experienced orthopedic radiologists to determine the location and extent of osteolytic lesions according to the specified zonal classifications, and any discrepancies were resolved by consensus.

For volumetric analysis, CT scans were acquired using a standardized protocol, and the DICOM images were then imported into 3D Slicer for segmentation and 3D reconstruction of osteolytic lesions, allowing for precise volumetric calculations that overcome the limitations of 2D measurements.

Results

Patient demographics and implant survivorship (Table 1)

A total of 60 revised hips were analysed (30 cemented, 30 cementless).

Patients in the cemented group were significantly older at the time of revision than those in the cementless group (median 77.5 vs 66.0 years; $p < 0.001$). Body mass index was modestly lower in the cemented group (median 25.5 vs 27.6 kg/m^2; $p = 0.026$).

Time in situ before revision was substantially longer for cemented THA (median 20.0 vs 13.0 years; $p < 0.001$), indicating that cemented implants tended to be revised later than cementless implants.

Table 1. Summarises the demographic and survivorship data.

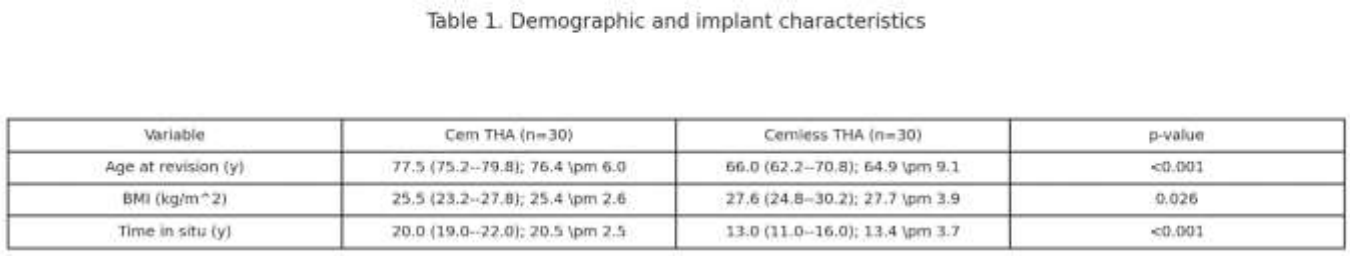

Table 1. Demographic and implant characteristics

Variable	Cem THA (n=30)	Cemless THA (n=30)	p-value
Age at revision (y)	77.5 (75.2--79.8); 76.4 \pm 6.0	66.0 (62.2--70.8); 64.9 \pm 9.1	<0.001
BMI (kg/m^2)	25.5 (23.2--27.8); 25.4 \pm 2.6	27.6 (24.8--30.2); 27.7 \pm 3.9	0.026
Time in situ (y)	20.0 (19.0--22.0); 20.5 \pm 2.5	13.0 (11.0--16.0); 13.4 \pm 3.7	<0.001

Volumetric osteolysis (Table 2A; Figures 1–2)

Cementless hips demonstrated substantially larger osteolytic volumes than cemented hips at the time of revision.

Femoral osteolytic volume was significantly higher in cementless THA (median 23.6 cm³, IQR 14.6–34.7) compared with cemented THA (median 5.2 cm³, IQR 2.9–8.7; $p < 0.001$).

Acetabular osteolytic volume was also greater in cementless hips (median 53.8 cm³, IQR 24.9–71.4) than in cemented hips (median 15.4 cm³, IQR 12.7–31.1; $p < 0.001$).

Consequently, total osteolytic volume (femoral + acetabular) was nearly threefold higher in the cementless group (median 72.8 cm³, IQR 47.7–107.4) compared with the cemented group (median 23.9 cm³, IQR 17.2–37.8; $p < 0.001$).

Table 2A. Volumetric osteolysis.

These differences are illustrated with boxplots and violin plots (Figures 1 and 2).

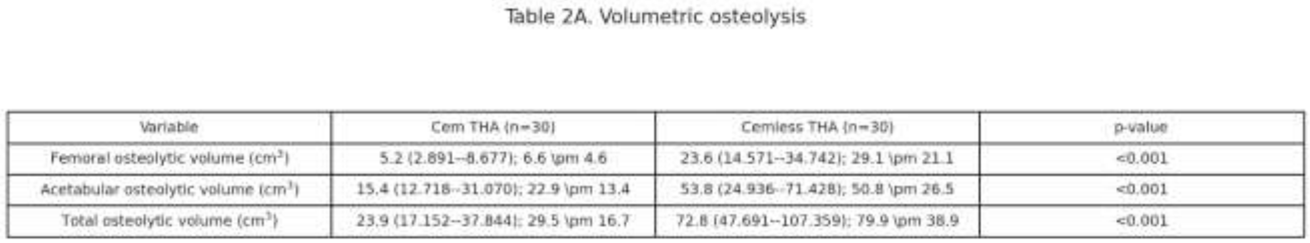

Table 2A. Volumetric osteolysis

Variable	Cem THA (n=30)	Cemless THA (n=30)	p-value
Femoral osteolytic volume (cm^3)	5.2 (2.891--8.677); 6.6 \pm 4.6	23.6 (14.571--34.742); 29.1 \pm 21.1	<0.001
Acetabular osteolytic volume (cm^3)	15.4 (12.718--31.070); 22.9 \pm 13.4	53.8 (24.936--71.428); 50.8 \pm 26.5	<0.001
Total osteolytic volume (cm^3)	23.9 (17.152--37.844); 29.5 \pm 16.7	72.8 (47.691--107.359); 79.9 \pm 38.9	<0.001

Femoral, acetabular, and total osteolytic volumes in cemented and cementless total hip arthroplasty (THA). Values are presented as median (interquartile range) and mean ± standard deviation. Cementless THA demonstrated substantially greater femoral, acetabular, and total osteolytic volumes than cemented THA, despite a shorter time in situ. All between-group comparisons were statistically significant.

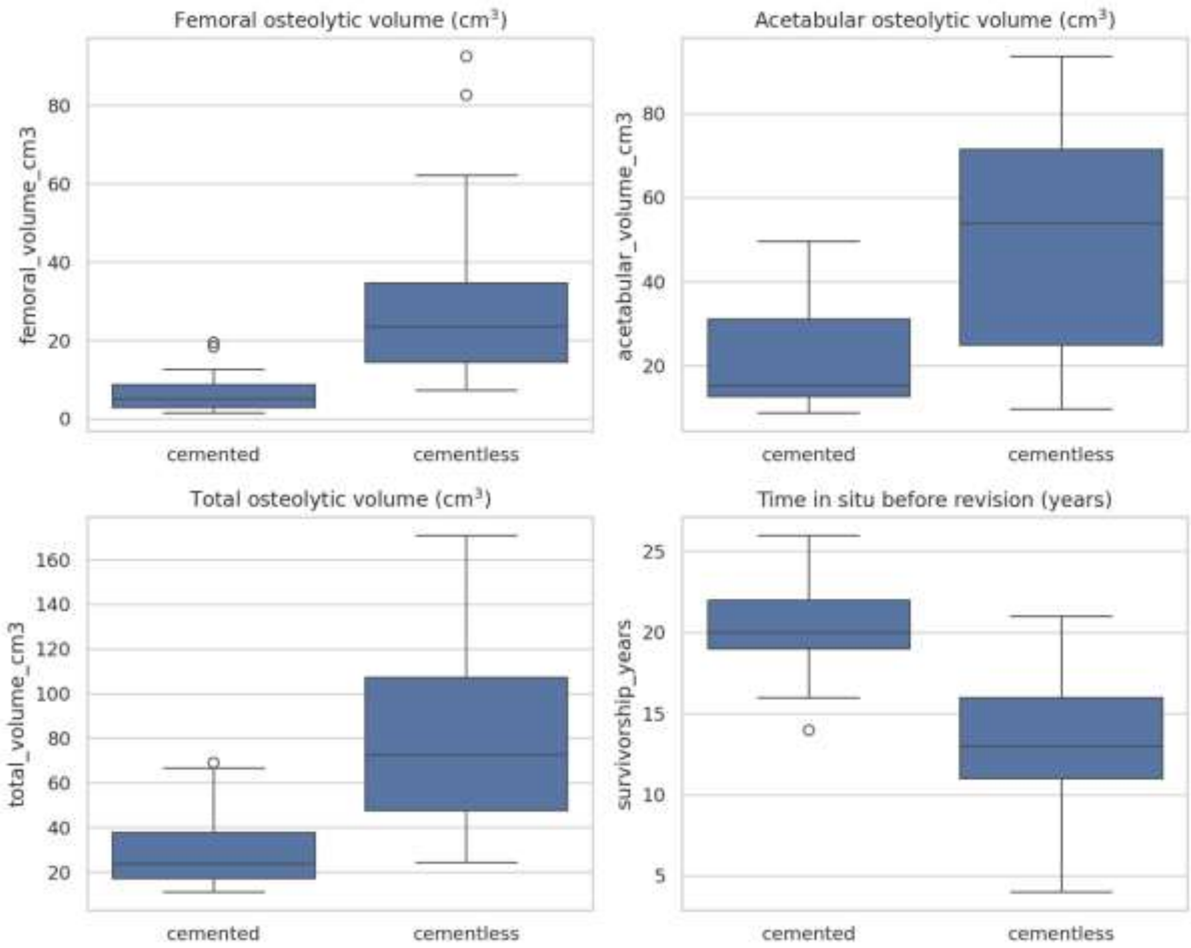

Figure 1. Demographic and implant characteristics

Comparison of age at revision, body mass index (BMI), and time in situ before revision between cemented and cementless total hip arthroplasty (THA). Box-and-whisker plots illustrate that patients revised after cemented THA were older and had implants in situ for longer than those revised after cementless THA, whereas BMI was slightly higher in the cementless group. Boxes represent interquartile ranges, horizontal lines the median, and whiskers the data range.

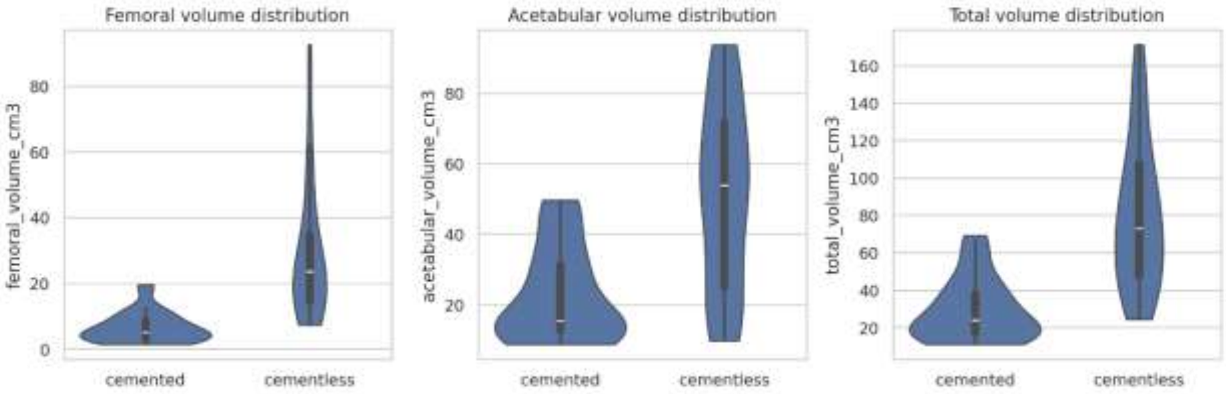

Figure 2. Volumetric osteolysis by fixation type Femoral, acetabular, and total osteolytic volumes in cemented and cementless total hip arthroplasty (THA). Box-and-whisker plots demonstrate markedly larger osteolytic volumes in cementless THA for both the femur and acetabulum, as well as for total osteolytic burden.

Despite a shorter time in situ, cementless implants developed substantially greater osteolytic volume than cemented implants. Boxes represent interquartile ranges, horizontal lines the median, and whiskers the data range.

Zonal distribution of osteolysis (Table 2B; Figure 3)

The distribution of osteolysis differed by fixation type for several femoral and acetabular zones.

On the femoral side (Gruen zones), cementless THA showed significantly higher proportions of hips with osteolysis in:

Gruen zone 1 (100.0% vs 60.0%, $p < 0.001$),
Gruen zone 2 (76.7% vs 23.3%, $p < 0.001$),
Gruen zone 3 (43.3% vs 10.0%, $p = 0.009$).

In contrast, cemented THA had significantly more osteolysis in Gruen zone 6 (70.0% vs 33.3%, $p = 0.010$). No significant group differences were observed in Gruen zones 4, 5, or 7.

On the acetabular side (DeLee–Charnley zones), cementless THA had a markedly higher frequency of osteolysis in DeLee–Charnley zone 1 (90.0% vs 43.3%, $p < 0.001$), whereas zones 2 and 3 showed similar involvement between groups (both 70–80%, $p = 1.000$).
These patterns are summarized in Table 2B and visualized as a grouped bar chart in Figure 3.

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Table 2B. Zonal distribution of osteolysis.

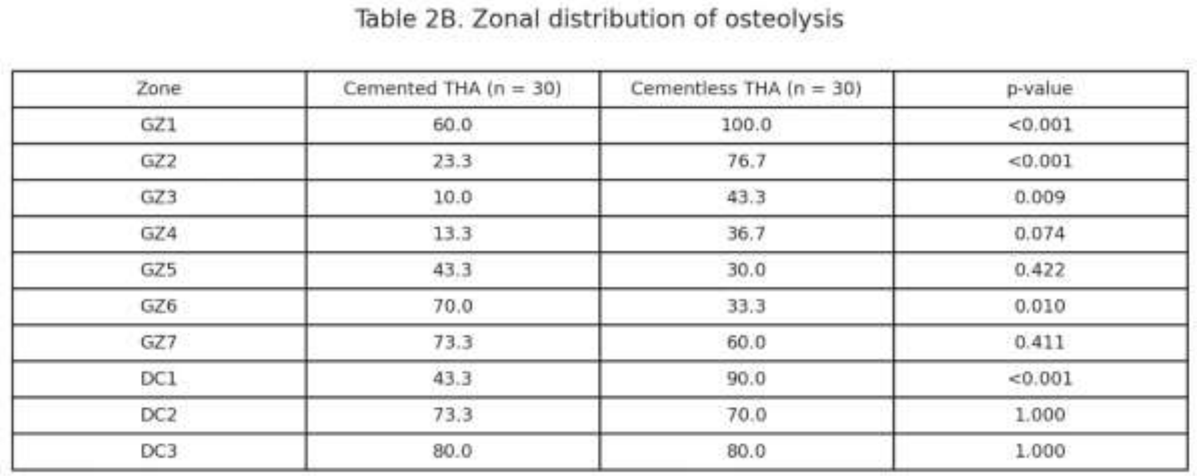

Table 2B. Zonal distribution of osteolysis

Zone	Cemented THA (n = 30)	Cementless THA (n = 30)	p-value
GZ1	60.0	100.0	<0.001
GZ2	23.3	76.7	<0.001
GZ3	10.0	43.3	0.009
GZ4	13.3	36.7	0.074
GZ5	43.3	30.0	0.422
GZ6	70.0	33.3	0.010
GZ7	73.3	60.0	0.411
DC1	43.3	90.0	<0.001
DC2	73.3	70.0	1.000
DC3	80.0	80.0	1.000

Zonal distribution of osteolysis in cemented and cementless total hip arthroplasty (THA). Data are expressed as the percentage of hips with radiographic osteolysis in each Gruen zone (1–7) and DeLee–Charnley zone (1–3).

Cementless THA showed a higher frequency of osteolysis in several proximal femoral zones and in the acetabular DeLee–Charnley zone 1, while cemented THA more often involved distal femoral zones. P-values indicate differences in the proportion of hips with osteolysis between cemented and cementless THA for each zone.

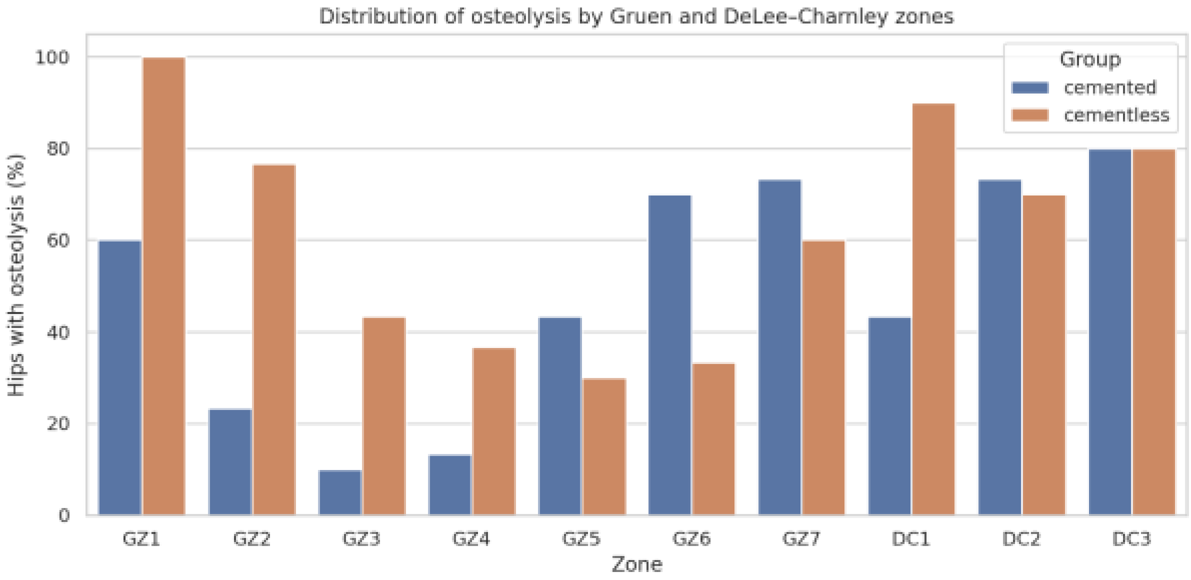

Figure 3. Zonal distribution of osteolysis

Proportion of hips with osteolysis in each Gruen zone (1–7) and DeLee–Charnley zone (1–3) for cemented and cementless total hip arthroplasty (THA).

Bar charts show distinct patterns of osteolysis, with cementless THA more frequently involving proximal femoral zones and the superolateral acetabular zone (DeLee–Charnley zone 1), while cemented THA shows relatively greater involvement of some distal femoral zones. Error bars, where present, indicate 95% confidence intervals.

Relationship between osteolytic volume and time in situ (Figure 4)

Scatter plots of total and femoral osteolytic volume versus time in situ showed that, despite cemented implants being in situ longer, cementless implants tended to accumulate larger volumes of osteolysis at earlier time points. This supports the volumetric findings above and suggests a different pattern of bone loss by fixation type. These relationships are illustrated in Figure 4.

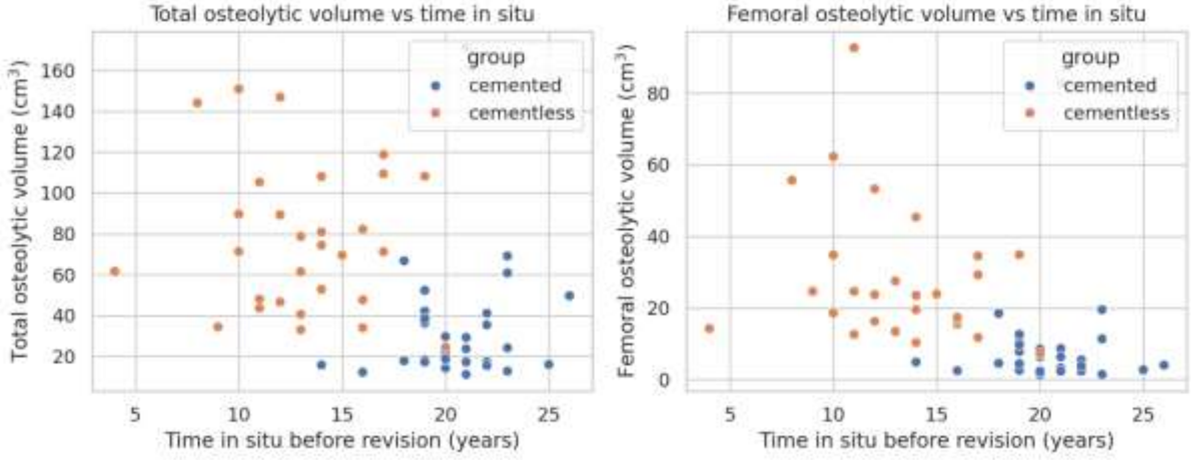

Figure 4. Relationship between osteolytic volume and time in situ

Scatterplots of total osteolytic volume versus time in situ before revision for cemented and cementless total hip arthroplasty (THA).

Each point represents a single hip. Cementless THA generally exhibits higher osteolytic volumes at shorter times in situ compared with cemented THA, suggesting a more aggressive pattern of osteolysis around cementless implants.

Discussion

Osteolysis remains a major long-term complication regardless of fixation method and the radiological presentations of osteolysis, even though extensively described, continue to present diagnostic challenges. The comparison between cemented and cementless fixation has been a well-studied topic in arthroplasty literature and yet, consensus regarding the distinct radiographic patterns and progression of osteolytic lesions is still evolving.

Influence of Fixation Method on Osteolytic Volume and Rate of Bone Loss

The most striking results of this study was the large disparity in volumetric osteolysis between the two fixation types. Cementless implants accumulated significantly greater femoral and acetabular bone loss despite a seven-year shorter median time in situ which suggests that cementless constructs not only permit but may potentiate a more aggressive osteolytic response.

Porous-coated stems and cups create periprosthetic microenvironments in which fluid pressure, micromotion and particle distribution differ fundamentally from cemented constructs.

These features probably accelerate endosteal and cancellous bone resorption once wear debris becomes biologically active.

This study confirms that fixation method has a material impact on periprosthetic bone resorption kinetics and is consistent with emerging evidence that cementless constructs are particularly vulnerable to extensive periprosthetic bone loss when osteolysis occurs[15].

The finding that cementless hips exhibited substantially greater volumetric osteolysis in both femoral and acetabular regions despite a shorter in situ time supports the mechanistic hypothesis that porous fixation creates a distinct fluid–particle environment that can amplify endosteal and cancellous bone resorption once polyethylene debris becomes biologically active [16,17].

In contrast, the smaller, more slowly progressive, and relatively distal lesions seen in cemented THA are consistent with prior work suggesting that the cement mantle can both alter the distribution of particulate debris and partially shield periprosthetic bone from the full hemodynamic and mechanical effects of joint fluid pressurization [16,18].

Topographic Patterns and Biomechanical Implications

The predominance of proximal femoral lesions in Gruen zones 1–3 around cementless stems parallels reports that uncemented metaphyseal-engaging designs can channel joint fluid and wear particles into the proximal endosteal canal, particularly in the presence of micromotion or imperfect osseointegration [17,19].

The porous-coated architecture of cementless stems creates a microenvironment with altered fluid pressure dynamics and particle distribution compared to the well-defined cement–bone interface of cemented constructs, facilitating accelerated endosteal and cancellous bone resorption [16,17].

Conversely, the more distal and often smaller defects associated with cemented stems reflect the biological behavior at the bone–cement mantle interface, where PMMA particles themselves contribute to the foreign-body inflammatory response while simultaneously acting as a partial mechanical barrier to proximal load transfer [18-20].

On the acetabular side, the dominance of DeLee–Charnley zone 1 involvement in cementless cups corresponds to the classical superolateral wear pattern described in long-term THA follow-up studies and is consistent with the superior loading mechanics of porous-coated hemispherical shells [17-21].

Recent series with highly cross-linked polyethylene (HXLPE) similarly report that while the absolute incidence of osteolysis has declined, lesions that do occur can still be voluminous and clinically significant in cementless designs, particularly when implants are revised at longer intervals [19].

This underscores that improved polyethylene formulations have reduced debris generation but have not eliminated the biological susceptibility of cementless interfaces to accelerated osteolytic responses.

Several experimental and clinical series have documented that polyethylene wear and synovitis correlate strongly with osteolytic burden, but most have focused on linear wear rates and radiographic defect scoring rather than three-dimensional volumetric characterization as employed in the present investigation [16,17].

Earlier reports comparing cemented and cementless fixation often reached conflicting conclusions on whether one method truly "prevents" osteolysis, largely because they relied on two-dimensional radiographs, heterogeneous imaging protocols, and qualitative grading systems that limited precision and reproducibility [16-18].

By applying standardized CT-based segmentation and volumetric assessment, this study extends that evidence base by demonstrating quantitatively that once osteolysis is established, its three-dimensional extent is disproportionately greater around cementless stems and cups, even when exposure time is substantially shorter.

Methodological Contribution and Standardization

A significant contribution of this study is the application of a uniform, CT-based three-dimensional workflow to quantify osteolytic volume and distribution, directly addressing one of the most frequently cited limitations in the prior literature: the poor sensitivity and reproducibility of plain radiographs for detecting and monitoring periprosthetic bone loss [16-22].

Advanced image processing platforms such as 3D Slicer enable semi-automated segmentation, reduction of metal artefact-related uncertainty through validated algorithms, and direct volumetric measurement, which together strengthen internal validity and minimize observer bias and projectional artefacts that can confound group comparisons [22,23].

The high interobserver reproducibility achieved through standardized segmentation protocols (as reflected in kappa or intraclass correlation metrics) demonstrates that volumetric assessment of osteolysis can be reliably integrated into clinical practice and research workflows.

The methodological standardization demonstrated here aligns with recent recommendations in orthopedic imaging literature advocating for the adoption of CT-based volumetric techniques as the gold standard for osteolysis assessment [23].

Integrating such high-resolution volumetric imaging into routine surveillance has the potential to harmonize research methodologies across centers, facilitate pooled analyses and meta-analyses, and support the creation of evidence-based osteolysis quantification protocols that future multicenter studies can adopt for consistent outcome reporting.

Clinical Decision-Making and Patient Selection

Clinically, the observation that cemented THA carried a substantially lower osteolytic burden despite longer implantation time (nearly a decade longer on average) reinforces the notion that cemented fixation remains a rational and durable option, particularly in elderly patients and those with compromised bone stock in whom preservation of periprosthetic bone architecture is critical for potential future revisions [17-19].

The data presented here support a more nuanced approach to implant selection that considers not only implant survivorship but also the biological behavior of the fixation method with respect to osteolysis progression. For patients with risk factors for accelerated osteolysis—including higher activity levels, younger age at primary surgery, or expected prolonged life expectancy—the choice between cemented and cementless fixation may merit reconsideration in light of the volumetric bone loss data herein.

At the same time, the more aggressive and proximally oriented bone loss observed in cementless hips underscores the critical need for earlier and more intensive imaging surveillance, including CT-based monitoring, to detect silent lytic lesions before they reach thresholds for catastrophic structural compromise or periprosthetic fracture [16-22].

The finding that cementless implants develop larger lesions in shorter timeframes suggests that routine radiographic screening protocols optimized for cemented implants may be insufficient, and that risk stratification algorithms incorporating fixation method should inform surveillance intensity and timing.

Revision Thresholds and Imaging Strategy

The observed differences in osteolytic magnitude and distribution between fixation types have direct and important implications for postoperative monitoring protocols and revision decision-making. Our findings support the implementation of targeted, more frequent radiographic and CT surveillance in cementless THA, with particular attention to the proximal femur and superolateral acetabulum where lesions are most likely to develop silently and progress rapidly [16-22].

Importantly, the use of standardized CT imaging performed under uniform acquisition and reconstruction protocols offers methodological and clinical advantages by improving reproducibility and reliability, allowing for detection of true pathological changes rather than artefactual differences in technique and interpretation [23].

When imaging is performed under consistent conditions with validated segmentation algorithms, intergroup comparisons become more valid and potential bias to one group is minimized, supporting evidence-based revision timing algorithms.

The quantification of volumetric bone loss using platforms such as 3D Slicer provides more accurate and clinically relevant measures of true periprosthetic bone loss compared to linear wear measurements or radiographic grading systems, and enables the definition of lesion-size thresholds above which revision intervention should be strongly considered, even in asymptomatic patients [22,23].

Study Limitations and Context

This study has several limitations that warrant acknowledgment. CT scans, while more accurate than plain radiographs, can be affected by metal artefacts that may obscure fine anatomic details even with reduction protocols; however, the use of medium bone algorithms and standardized reconstruction parameters minimizes this effect [22,23].

Despite standardized protocols, segmentation and interpretation of results can be influenced by observer experience and subjective selection criteria, though blinded review and interobserver reliability testing mitigate this concern. Another potential limitation stems from differences in implant manufacturer, polyethylene quality (conventional vs. HXLPE), femoral head material, and cup design between the cemented and cementless groups, which could confound the direct comparison of fixation methods; multivariate regression modeling adjusting for these factors is essential for attributing observed differences to fixation method alone [19].

Additionally, the cross-sectional nature of revision cohorts inherently introduces selection bias, as cases represent only those patients who reached revision thresholds and may not reflect the full spectrum of osteolytic behavior in unrevised implants followed prospectively to longer intervals.

Implications for Future Research

This study highlights important distinctions in the characteristics and kinetics of osteolysis between cemented and cementless THA; however, it also underscores the critical need for larger, prospectively designed investigations to confirm and refine these observations in contemporary cohorts [19,24].

Future research should incorporate multicenter collaboration, more diverse patient demographics, and contemporary implant designs and bearing materials to ensure generalizability to current clinical practice. High-resolution volumetric imaging and standardized osteolysis quantification protocols should be integrated systematically into prospective studies to map the evolution of lesion magnitude and distribution over extended follow-up intervals, capturing the natural history from primary implantation through potential revision [22,23].

Such work would allow for the development of predictive models that incorporate fixation method, polyethylene type, bearing surface, patient factors, and activity level to define individual risk trajectories for osteolysis development and enable evidence-based risk stratification tools and guidelines for imaging intervals and revision thresholds tailored to each patient's biologic and mechanical risk profile [19,24].

Additionally, longitudinal studies incorporating both volumetric imaging and biomarkers of periprosthetic inflammation (e.g., synovial fluid cytokine profiles, serum metal or polyethylene particle concentrations) may clarify the temporal relationship between wear-particle generation, tissue inflammation, and osteoclastic activation, potentially enabling early intervention strategies before extensive bone loss occurs.

Conclusion

This study demonstrates definitively that fixation method profoundly influences the magnitude, distribution, and progression rate of osteolysis in THA. Cementless implants develop larger and earlier osteolytic lesions, particularly in the proximal femur and superolateral acetabulum, while cemented implants exhibit smaller, more slowly progressive lesions with a more distal distribution pattern.

These distinctions reflect fundamental differences in the periprosthetic biomechanical and fluid-dynamic environment created by each fixation strategy and have direct implications for patient selection, surveillance methodology, and revision decision-making.

The application of standardized CT-based volumetric assessment provides a more precise and reproducible approach to monitoring osteolysis progression than traditional radiographic methods and supports the development of evidence-based, fixation-specific guidelines for imaging intervals and revision thresholds.

In an era in which cementless fixation continues to dominate global practice, these findings reinforce the importance of rigorous long-term surveillance and suggest that individualized implant selection based on patient age, bone quality, activity level, and life expectancy may optimize long-term durability and minimize the burden of periprosthetic bone loss.

LIST OF ABBREVIATIONS

Abbreviation Full Term
3D Slicer - Three-Dimensional Slicer
BMI - Body Mass Index
CT - Computed Tomography
DICOM - Digital Imaging and Communications in Medicine
FTIR - Fourier Transform Infrared
HXLPE - Highly Cross-Linked Polyethylene
ICC - Intraclass Correlation Coefficient
IQR - Interquartile Range
IRB - Institutional Review Board
MMPs - Matrix Metalloproteinases
MRI - Magnetic Resonance Imaging
PMMA - Polymethylmethacrylate
SPECT - Single-Photon Emission Computed Tomography
THA - Total Hip Arthroplasty
UHMWPE - Ultra-High Molecular Weight Polyethylene
cm^3 - Cubic Centimeters

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