Park *et al. BMC Musculoskeletal Disorders* (2025) 26:1010
https://doi.org/10.1186/s12891-025-09249-9

BMC Musculoskeletal Disorders

RESEARCH Open Access

Comparison of mechanical and clinical outcomes between cement-augmented and conventional cephalomedullary nailing in osteoporotic trochanteric fractures: a propensity score-matched cohort study

Jun Young Park[1*], Tae Kang Kim[2], Byung Woo Cho[3], Hyuck Min Kwon[4], Kwan Kyu Park[4] and Woo-Suk Lee[3]

Abstract

Background Trochanteric fractures in the older population are challenging to treat due to osteoporotic bone and high risk of fixation failure. Cement augmentation (CA) of cephalomedullary fixation has been proposed to enhance implant anchorage and reduce complications. This study compared mechanical failure rates and clinical outcomes between cement-augmented and conventional cephalomedullary nailing in osteoporotic trochanteric fractures.

Methods We performed a retrospective comparative study of patients with trochanteric fractures treated with either a CA or non-CA cephalomedullary nail from February 2022 to July 2023. To minimize selection bias, 1:2 propensity score matching was applied to our initial 143 consecutive cases (28 CA, 115 non-CA), yielding 28 augmented and 56 conventional cases. The primary outcome was the rate of implant cut-out. Secondary outcomes were excessive telescopic sliding, 1-year mortality, and patient-reported outcome measures using Harris Hip Score (HHS) and EuroQol 5-Dimension (Eq. 5D) at the final follow up.

Results After matching, the CA group had no instances of cut-out (0/28), compared to 1 case (1/56, 1.8%) in the non-CA group ($p = 1.00$), though the study was underpowered for this rare outcome, with mean follow-up periods of 19.2 ± 18.3 weeks and 23.0 ± 22.5 weeks, respectively. Excessive sliding of the proximal screw occurred in 3 patients (10.7%) with CA versus 7 (12.5%) without ($p = 1.00$) during the same follow-up period, while 1-year mortality was similar between groups (CA 25.0% vs. non-CA 19.6%, $p = 0.78$). Final follow-up HHS and Eq. 5D scores were similar between the CA and non-CA groups. No cement-related complications, such as leakage or thermal injury, were observed in this cohort.

Conclusions Cement augmentation of a cephalomedullary nail demonstrated comparable mechanical outcomes in terms of cut-out and excessive sliding, as well as similar 1-year mortality and functional outcomes to conventional fixation. This process with a cephalomedullary nail appears to be a safe and effective option for older patients with

*Correspondence:
Jun Young Park
jjunyon@yuhs.ac

Full list of author information is available at the end of the article

a trochanteric fracture and shows no postoperative complications. Further large prospective studies are needed to identify patients expected to benefit most from CA.

Trial registration not applicable.

Keywords Cement augmentation, Trochanteric fracture, Cephalomedullary nail, Cut-out, Osteoporotic hip fracture

Background

Trochanteric fractures represent one of the most common and challenging fragility fractures in the older population [1, 2]. These fractures occur predominantly in osteoporotic bone, hindering stable fixation [3, 4]. The standard treatment typically involves internal fixation with cephalomedullary nails, which provide biomechanical advantages through load-sharing across the fracture site [5, 6]. However, fixation failure, such as cut-out of the lag screw or helical blade, remains a concern in cephalomedullary nailing, with failure rates reported at 2–15% depending on bone quality and fracture characteristics [5, 7].

Cement augmentation (CA) of cephalomedullary fixation is a potential technique to enhance construct stability in osteoporotic bone [8]. This procedure involves injection of polymethylmethacrylate (PMMA) bone cement through perforations in the proximal screw into the surrounding cancellous bone of the femoral head. Biomechanical studies have consistently demonstrated that CA significantly increases the resistance to cut-out under cyclic loading and shifts stress distribution patterns to reduce micromotion at the bone-implant interface [9, 10]. This is particularly beneficial in unstable fracture patterns with compromised lateral wall integrity, where traditional fixation methods show higher failure rates [11, 12].

Several observational studies have reported trends toward fewer reoperations or mechanical complications with augmentation, particularly in highly osteoporotic patients [13, 14]. Notably, a multicenter randomized controlled trial reported no significant improvement in early postoperative mobility with CA but noted zero mechanical failures in the augmented group compared to a 5% reoperation rate in controls [15]. Other studies have reported improved early weight-bearing ability with augmentation [12, 16], although functional outcomes and pain scores show variable results across investigations [11, 17]. Concerns regarding potential complications such as cement leakage, thermal necrosis, or difficulties with revision surgery have also been raised, though recent evidence suggests that the technique is generally safe when properly executed [8, 18].

Despite promising biomechanical data, clinical evidence supporting the efficacy of CA remains inconclusive, particularly in Asian populations where relevant studies are lacking. Our study aims to address this clinical imbalance by comparing the mechanical and clinical outcomes of CA vs. non-CA cephalomedullary fixation in trochanteric fractures, with a primary focus on cut-out rates and secondary attention to excessive implant sliding, 1-year mortality, and mobility status at the final follow-up.

Methods

Study design and patients

We conducted a retrospective comparative study at a regional university-affiliated referral hospital. After Institutional Review Board approval (9–2025-0048), we identified 182 patients who underwent cephalomedullary nailing for a hip fracture between February 2022 and July 2023. Inclusion criteria were patients diagnosed with trochanteric fractures classified as AO/OTA type 31-A1, A2, or A3, treated with a proximal femoral cephalomedullary nail. Exclusion criteria were pathological fractures, atypical femoral fractures, concomitant ipsilateral lower extremity injuries, revision surgeries for prior hip fracture fixation, or follow-up shorter than 3 months. Among these patients, 28 patients underwent CA based on preoperative and intraoperative assessment. All patients had preoperative bone mineral density measurement by dual-energy X-ray absorptiometry scanning. Patients were considered for CA if they had: (1) severe osteoporosis (T-score ≤ – 2.5) with poor cortical quality on radiographs; (2) unstable fracture patterns (AO/OTA 31-A2 with lateral wall incompetence or 31-A3); and/or (3) intraoperative findings of poor implant purchase, severe comminution, or inadequate reduction stability. The final decision was made by the attending surgeon based on the combination of these factors. The remaining 115 patients underwent standard cephalomedullary nailing without augmentation (non-CA group). The patient selection process and exclusion criteria are illustrated in Fig. 1.

Surgical technique

All patients underwent fracture fixation in the supine position on a traction table under fluoroscopic guidance. In the CA group, bone cement was injected through the cannulated implant (TFNA, DePuy Synthes) using the TRAUMACEM™ V + Augmentation System (DePuy Synthes, Raynham, MA, USA). Although based on PMMA, the cement formulation includes zirconium dioxide for radiopacity and hydroxyapatite to enhance biocompatibility. We used a standardized cement volume of

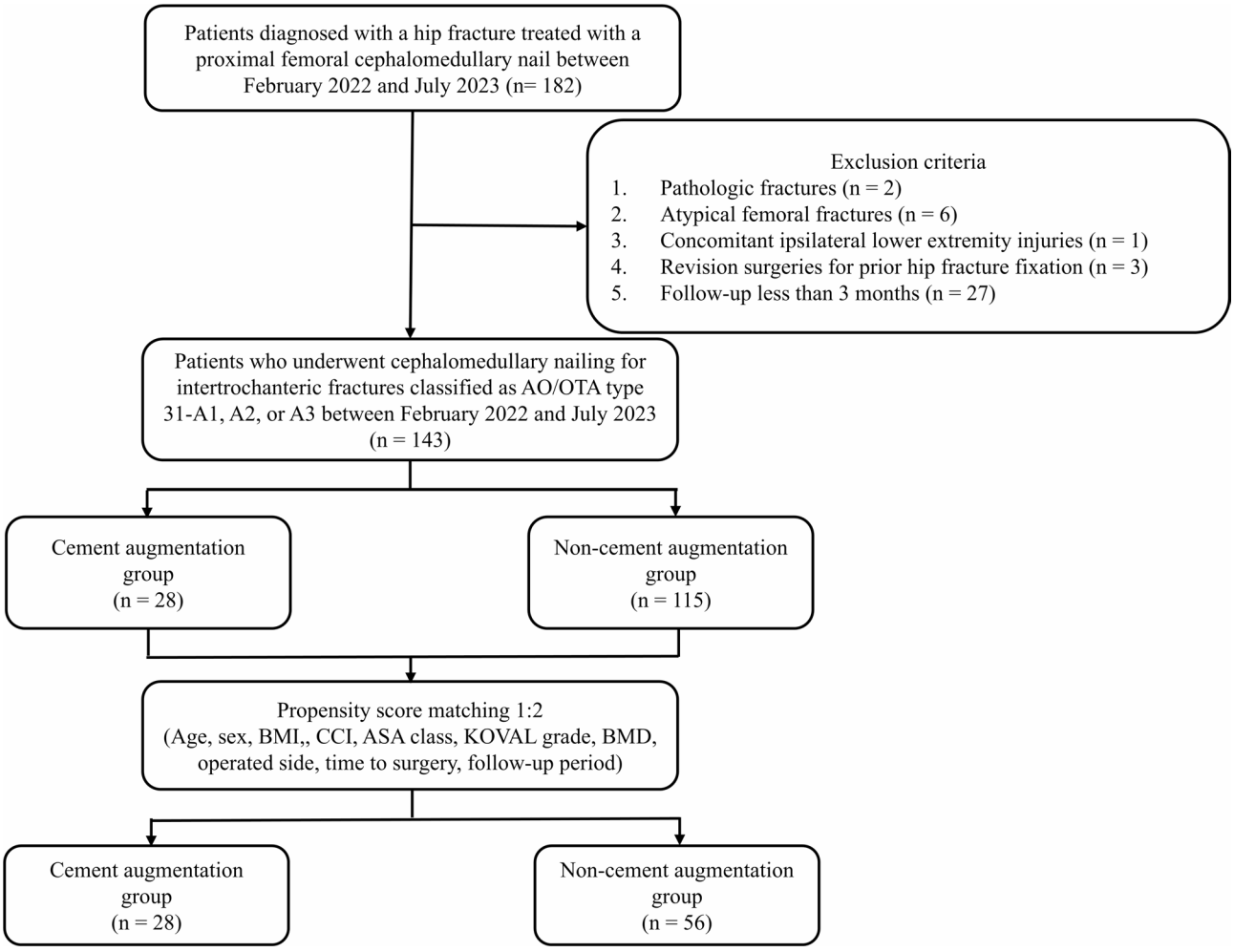

Fig. 1 CONSORT flow diagram of patient selection

approximately 4 mL (range, 3–5 mL) per case, adjusted according to the patient's femoral head size and delivered via a pressure syringe once the implant was in the final position, following the manufacturer's technique for a fenestrated nail. The cement was allowed to polymerize for a few minutes before completing distal locking. In the non-CA group, nails were placed in standard fashion without cement injection. All surgeries were performed by a single orthopedic surgeon specializing in hip trauma. Postoperatively, patients in both groups were mobilized weight-bearing as tolerated in accordance with our geriatric fracture protocol, unless the surgeon specified partial weight-bearing due to fracture complexity or poor fixation purchase. Thromboprophylaxis and standard postoperative care for hip fracture were applied uniformly. A representative case example is illustrated in Fig. 2, showing a 97-year-old female patient with an intertrochanteric fracture treated with cement-augmented TFNA, demonstrating the surgical technique and satisfactory healing at 1-year follow-up.

Outcomes and definitions

The primary outcome was implant cut-out, defined radiographically as migration of the proximal screw leading to protrusion from the femoral head superiorly into the joint or through the cortex [19]. All postoperative pelvis and hip radiographs obtained at routine follow-up intervals of 1 month, 3 months, 6 months, and 1 year, as well as at any unscheduled visits, were reviewed for evidence of cut-out. The secondary outcomes were excessive sliding of the proximal screw, 1-year mortality, and patient-reported outcome measures using Harris Hip Score (HHS) and EuroQol 5-Dimension (Eq. 5D) at the final follow-up. We defined excessive sliding as >15 mm of telescoping of the lag screw or helical blade measured on final follow-up radiographs according to previous studies [20–22]. This mechanical measurement represents the shortening distance of the implant within the femoral head and neck, which may occur independently of fracture reduction quality. 1-year mortality was determined based on hospital records and national health

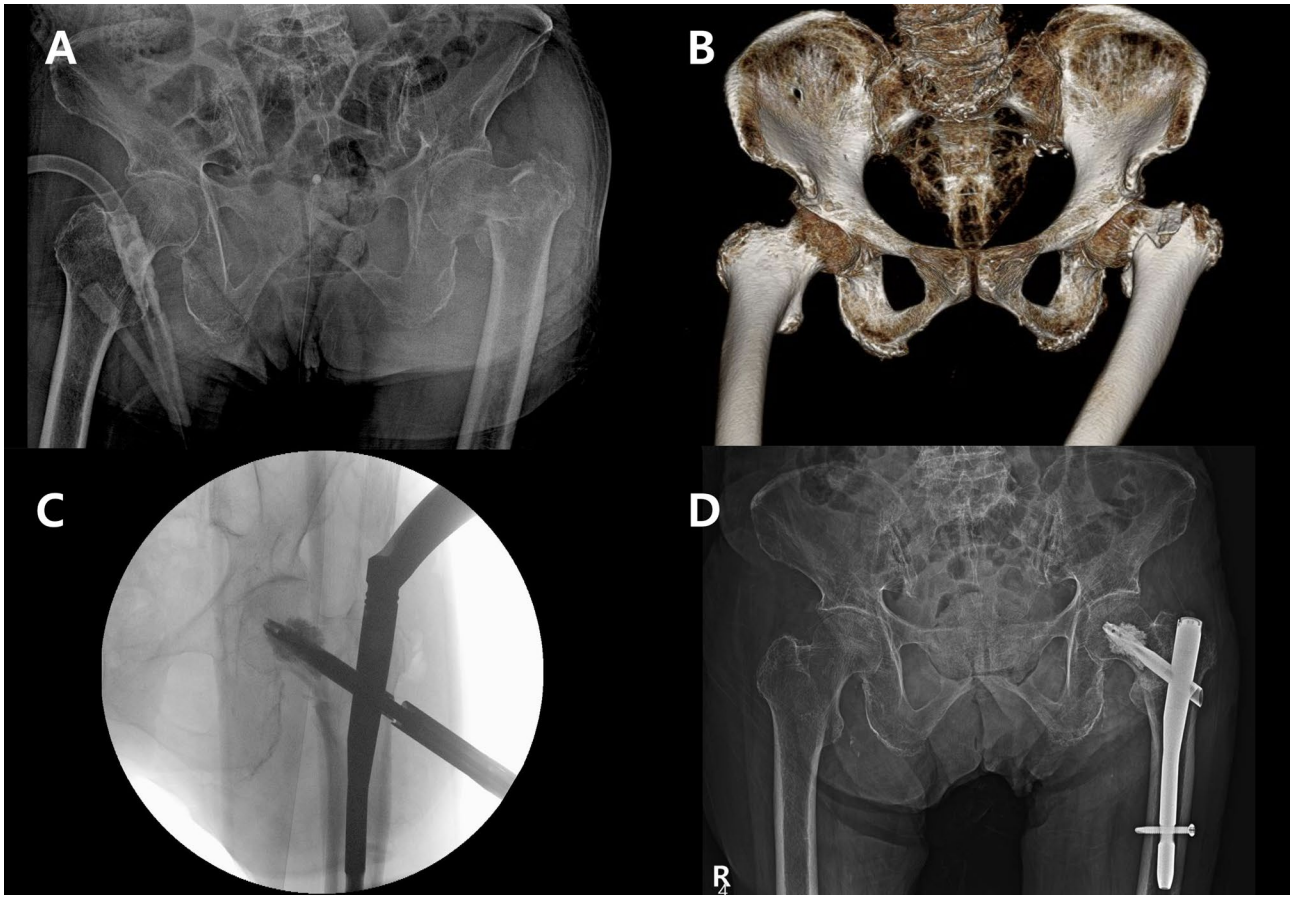

Fig. 2 Case example of cement-augmented cephalomedullary fixation for a trochanteric fracture in a 97-year-old female **A** and **B**: preoperative plain radiograph and 3D reconstructed CT image, **C**: intraoperative view of cement augmentation, **D**: 1-year postoperative radiograph

insurance disenrollment data, using the date of insurance eligibility loss as a surrogate marker for death.

We additionally assessed radiographic reduction quality and implant positioning on the immediate postoperative films [23]. The tip apex distance (TAD) was measured as the sum of distances from the tip of the proximal screw to the apex of the femoral head on anteroposterior (AP) and lateral views [24]. We also calculated the calcar-referenced tip apex distance (Cal-TAD) to account for the position of the tip relative to the inferomedial calcar on AP view. Placement of the implant within the femoral head was assessed using the Cleveland zone classification on both AP and lateral views [25]. The center-center position was defined as the reference category, representing the optimal placement. Positions adjacent to the center–center were grouped as +, indicating acceptable placement, whereas peripheral or malpositioned zones were classified as x, indicating suboptimal positioning. Reduction quality was graded using the Chang reduction quality criteria, which evaluate fracture alignment and cortical continuity on AP and lateral radiographs [26]. Scores range from 0 to 4, with higher scores indicating better reduction. Based on prior literature, scores of 3 or 4 were considered anatomical, 2 as acceptable, and scores ≤ 1 as poor. These radiographic parameters were recorded by a fellowship-trained orthopedic traumatologist blinded to the study hypothesis.

Statistical analysis

Categorical variables were compared between groups using Fisher's exact test or chi-square test, as appropriate. Continuous variables were assessed for normality and compared using Student's t-test or Mann-Whitney U test. The primary analysis compared outcomes in the matched CA vs. non-CA groups. Significance was set at $\alpha = 0.05$ (two-tailed). Given the relatively small sample size, we also examined absolute differences and 95% confidence intervals. No a priori sample size calculation was performed due to the retrospective design; however, the study had low power to detect very rare events like cut-out. To reduce selection bias due to the non-random allocation of augmentation, we performed propensity score matching. The propensity score was derived from a logistic regression model for likelihood of CA based on baseline variables of age, sex, body mass index (BMI), Charlson Comorbidity Index (CCI), American Society

Table 1 Demographics of the study cohort before and after propensity score matching

	Before propensity score matching				After propensity score matching		
	Cement augmentation group	Conventional group	Total	*p*	Cement augmentation group	Conventional group	*p*
N, hips	28	115	143		28	56	
Age	86.5 ± 6.1	80.9 ± 9.8	82.0 ± 9.5	< 0.001	86.5 ± 6.1	85.1 ± 5.8	0.32
Female	24 (85.7%)	89 (77.4%)	113 (79.0%)	0.48	24 (85.7%)	46 (82.1%)	0.92
Body mass index	23.5 ± 4.0	22.1 ± 3.6	22.4 ± 3.7	0.09	23.5 ± 4.0	22.8 ± 2.9	0.43
CCI	5.3 ± 1.6	5.0 ± 1.1	5.1 ± 1.2	0.36	5.3 ± 1.6	5.2 ± 1.1	0.63
ASA class				0.43			0.29
2	1 (3.6%)	9 (7.8%)	10 (7.0%)		1 (3.6%)	5 (8.9%)	
3	27 (96.4%)	102 (88.7%)	129 (90.2%)		27 (96.4%)	48 (85.7%)	
4	0 (0.0%)	4 (3.5%)	4 (2.8%)		0 (0.0%)	3 (5.4%)	
KOVAL scale	4.4 ± 1.7	4.1 ± 2.0	4.1 ± 1.9	0.50			
Bone mineral density, T-score	−3.0 ± 0.7	−3.0 ± 1.0	−3.0 ± 0.9	0.75	−3.0 ± 0.7	−3.1 ± 0.9	0.63
Operated side, right/left	17/11	50/65	67/76	0.15	17/11	34/22	1
Time to surgery, days	2.4 ± 2.0	3.8 ± 3.0	3.5 ± 2.9	< 0.05	2.4 ± 2.0	2.4 ± 1.5	0.94
Follow-up period, weeks	19.2 ± 18.3	33.5 ± 27.9	30.7 ± 26.8	< 0.01	19.2 ± 18.3	23.0 ± 22.5	0.49

CCI Charlson comorbidity index, *ASA* American Society of Anesthesiologists

Table 2 Comparison of fracture type, implant used, and postoperative reduction assessment between the two groups after propensity score matching

	After propensity score matching			
	Cement augmentation group	Conventional group	Total	*p*
N, hips	28	56	84	
AO/OTA classification				0.91
31.A1	8 (28.6%)	17 (30.4%)	25 (29.8%)	
31.A2	19 (67.9%)	36 (64.3%)	55 (65.5%)	
31.A3	1 (3.6%)	3 (5.4%)	4 (4.8%)	
Implant used				< 0.001
TNFA with cement	28 (100.0%)	0 (0.0%)	28 (33.3%)	
TFNA	0 (0.0%)	27 (48.2%)	27 (32.1%)	
PFNA	0 (0.0%)	16 (28.6%)	16 (19.0%)	
Gamma3	0 (0.0%)	13 (23.2%)	13 (15.5%)	
Tip apex distance, mm	18.9 ± 4.4	18.8 ± 4.8	18.8 ± 4.7	0.93
Calcar-referenced tip apex distance, mm	22.9 ± 3.6	21.7 ± 4.5	22.1 ± 4.2	0.25
Cleveland zone classification				0.36
Reference (optimal)	18 (64.3%)	27 (48.2%)	45 (53.6%)	
+ (acceptable)	9 (32.1%)	25 (44.6%)	34 (40.5%)	
x (suboptimal)	1 (3.6%)	4 (7.1%)	5 (6.0%)	
Chang score				0.71
0	0 (0.0%)	1 (1.8%)	1 (1.2%)	
1	0 (0.0%)	1 (1.8%)	1 (1.2%)	
2	2 (7.1%)	8 (14.3%)	10 (11.9%)	
3	7 (25.0%)	11 (19.6%)	18 (21.4%)	
4	19 (67.9%)	35 (62.5%)	54 (64.3%)	

TNFA Trochanteric Fixation Nail-Advanced, *PFNA* Proximal Femur Nail Antirotation, *AP* Anteroposterior

of Anesthesiologists (ASA) class, preoperative KOVAL scale, bone mineral density, operated side, time to surgery, and follow-up period. Patients in the CA group were matched to patients in the non-CA group with a caliper of 0.2 at a ratio of 1:2 using nearest-neighbor matching without replacement. All statistical analyses were conducted using R software, version 4.4.0.

Results

Prior to matching, patients selected for CA were significantly older than those in the conventional group (86.5 ± 6.1 vs. 80.9 ± 9.8 years, $p < 0.001$) (Table 1). Although not significant, there was a trend toward a higher proportion of female patients (85.7 vs. 77.4%, $p = 0.48$) and a higher BMI (23.5 ± 4.0 vs. 22.1 ± 3.6 kg/m^2, $p = 0.09$) in the CA group. After PSM, the CA group (28 patients) and the non-CA group (56 patients) were well matched, with no significant differences in demographic or clinical characteristics. The follow-up period was significantly shorter in the CA group before matching (19.2 ± 18.3 vs. 33.5 ± 27.9 weeks, $p < 0.01$) but was comparable between the two groups after matching (19.2 ± 18.3 vs. 23.0 ± 22.5 weeks, $p = 0.49$).

Radiographic measurements of postoperative reduction status were comparable between groups after PSM (Table 2). The AO/OTA classification showed no significant difference between the two groups ($p = 0.91$). In the non-CA group, three types of implants were used (TFNA, PFNA, and Gamma3) ($p < 0.001$). The mean TAD was 18.9 ± 4.4 mm in the CA group and 18.8 ± 4.8 mm in the non-CA group ($p = 0.93$), and the Cal-TAD was also similar (22.9 ± 3.6 vs. 21.7 ± 4.5 mm, $p = 0.25$). On the AP and lateral views, according to the Cleveland zone system, the lag screw or blade was positioned in the

Table 3 Mechanical and functional outcomes of cement-augmented vs. non-augmented cephalomedullary nailing groups after propensity score matching

	After propensity score matching		
	Cement augmentation group	Conventional group	*p*
N, hips	28	56	
Cut out	0 (0.0%)	1 (1.8%)	0.98
Excessive sliding	3 (10.7%)	7 (12.5%)	1.00
1-year mortality	7 (25.0%)	11 (19.6%)	0.78
HHS at baseline	25.2 ± 5.2	25.9 ± 6.1	0.58
HHS at postoperative 1 year	64.8 ± 10.4	64.1 ± 10.1	0.78
Eq. 5D at baseline	36.1 ± 2.5	36.7 ± 2.6	0.25
Eq. 5D at postoperative 1 year	63.7 ± 8.1	60.4 ± 8.7	0.10

HHS Harris Hip Score, *Eq. 5D* EuroQol 5-Dimension

reference or acceptable zone in 96.4% of cases in the CA group and 92.9% in the non-CA group ($p = 0.36$). Quality of fracture reduction assessed by the Chang score was comparable between the groups ($p = 0.71$), with anatomical or acceptable reduction achieved in 96.4% of the CA group and 94.6% of the non-CA group. The results between the two groups before PSM are presented in Supplementary Table 1 (Table 3).

The incidence of implant cut-out was comparable between the groups after matching, with no cases in the CA group (0 of 28 hips, 0%) and 1 case in the non-CA group (1 of 56 hips, 1.8%) ($p = 0.98$). We observed no significant difference in excessive fracture collapse between groups. Excessive sliding of the proximal screw was recorded in 3 patients (10.7%) with CA and 7 patients (12.5%) with non-CA fixation ($p = 1.00$), and 1-year mortality did not differ significantly between the groups. In the CA group, 7 of 28 patients (25.0%) died, compared to 11 of 56 (19.6%) in the non-CA group ($p = 0.78$). At the final follow-up, functional outcomes assessed by the HHS and Eq. 5D were comparable between the CA and non-CA groups (HHS 64.8 ± 10.4 vs. 64.1 ± 10.1, $p = 0.78$; EQ-5D 63.7 ± 8.1 vs. 60.4 ± 8.7, $p = 0.10$) after matching. Mechanical and clinical outcomes before PSM were presented in Supplementary Table 2. We did not observe any cement-related systemic or local complications such as fat embolism syndrome or intra-operative cement leakage and thermal damage in the CA group.

Discussion

We found no significant differences in mechanical outcomes including cut-out and excessive sliding or in functional outcomes such as 1-year mortality and final follow-up HHS and Eq. 5D between CA and non-CA cephalomedullary nailing in this matched cohort of trochanteric fractures. No cases of cut-out were observed in the CA group (0%), supporting the hypothesis that augmentation improves construct stability. Meanwhile, the non-CA group also showed a relatively low cut-out rate of 1.8% (1 of 56 hips), which is below the historically reported incidence of 2–6% with modern intramedullary devices [5, 6]. These findings suggest that, when proper surgical principles are applied, CA can achieve clinical outcomes comparable to those of conventional fixation. However, this study might have been underpowered to detect a significant difference due to the low event rate.

The protective mechanism of CA can be explained using biomechanical principles. When cement is injected around the proximal screw, it creates an interdigitated bone-cement cloud that supports the implant against toggling and varus tipping in the femoral head. Finite element analyses and cadaver studies show that injecting cement around the proximal screw markedly increases the force required for cut-out and reduces femoral head rotation or varus collapse under load [9, 10, 27]. The cement primarily limits micromotion at the bone-implant interface, particularly in low-bone-density conditions, stabilizing the construct [18, 27]. This stabilizing effect is especially important in highly osteoporotic bone, where traditional fixation might be compromised by poor purchase of the implant [18].

Our findings echo those of Kammerlander et al., who conducted a multicenter trial of 223 patients [15]. In their study, CA did not improve early functional outcomes, but no patient in the CA group required reoperation for mechanical failure, compared to six patients (5% of cases) in the non-CA group. Our study pattern is remarkably similar: no failures with augmentation vs. one without. These consistent findings suggest that augmentation can prevent the worst-case scenario of lag screw cut-out in extremely osteoporotic bone, even though the difference did not reach significance due to the already low failure rates achieved with current standards of care [17, 28].

Importantly, our data suggest that CA did not significantly reduce excessive sliding during fracture healing. Some surgeons worry that augmentation might overstabilize the fracture, preventing the desired impaction that contributes to secondary bone healing. In our series, however, the incidence of excessive sliding was comparable between the CA group (3 of 28, 10.7%) and the non-CA group (7 of 56, 12.5%) after matching ($p = 1.00$). This suggests that CA provides resistance mainly against gross failure but does not eliminate controlled subsidence of the fracture, which is beneficial for healing. Thus, concerns about rigid fixation with PMMA augmentation were not substantiated by our clinical observations. This aligns with findings by Mochizuki et al., who observed that augmented nails allowed earlier full weight-bearing with improved early functional scores compared to non-augmented nails, without compromising fracture healing [16].

Regarding safety, our results and the literature indicate that CA is a safe adjunct when used properly. We observed no cement-related complications such as emboli, deep infection, leakage, or avascular necrosis due to thermal damage. A meta-analysis by Mansour et al. pooling several studies found that CA nails do not increase perioperative complication rates compared to standard fixation [8], and no difference in mortality has been observed [13, 17]. The key to safe application is using the correct technique, including complete reduction before cement injection and careful monitoring of cement volume and distribution under fluoroscopy to avoid leakage [18]. In our series, we routinely limited cement to approximately 4 mL and did not encounter any significant extravasation, similar to the technique described by Dall'oca et al. [11].

The gap between the biomechanical improvements and clinical outcomes observed in our study may be attributed to a complex interplay of factors in the older population. Recent research by Olarte Salazar et al. found that, despite radiological improvements with cement augmentation, functional recovery was limited by factors other than mechanical stability [29]. This paradox can be explained by several factors specific to older patients. First, the physiological limitations of aging, including sarcopenia, impaired balance, and reduced physiological reserves, might override the benefits of improved implant stability. Studies show that pre-fracture functional status remains the strongest predictor of recovery, with Kulachote et al. finding that pre-injury ambulatory ability was the dominant factor influencing return to pre-fracture mobility, far outweighing the contribution of fixation technique [30]. Second, the relationship between bone stability and function appears to follow a threshold effect rather than a linear relationship. Once a minimum threshold of stability is achieved with modern implants and proper technique, additional biomechanical improvement from CA might not translate to proportional functional gain. This can explain why, despite the theoretical advantages of CA, the clinical differences in our study were minimal. The 1-year mortality rates were similar between groups, and PROMs at final follow-up also were comparable. Recent meta-analyses have shown that CA significantly reduces cut-out rates compared to conventional fixation only in patients with documented severe osteoporosis or highly unstable fracture patterns [8, 17]. Third, non-biomechanical factors significantly impact recovery regardless of fixation technique. Cognitive impairment, which is prevalent in hip fracture patients, limits participation in rehabilitation protocols. A recent study showed that moderate to severe cognitive impairment was associated with poorer functional outcomes regardless of fixation stability [31]. Similarly, multiple comorbidities, nutritional status, and social support systems strongly influence rehabilitation potential independent of fracture fixation quality [32]. These factors can explain why improved mechanical stability does not always translate to better functional outcomes in the older population.

Considerations of CA include the cost and logistics. Augmented nails and cement kits add expense and surgical time. Joeris et al. performed a cost-effectiveness analysis and concluded that CA was cost-saving in the long run by avoiding reoperations and late complications [33]. Their analysis found that fixation with augmentation reduced per-patient costs by approximately $750, primarily driven by reduced reoperation rates. Our study, with only 1 prevented failure, is too small to draw economic conclusions, but it lends qualitative support: even 1 less reoperation in a small cohort can justify the upfront cost of cement, given the high expense and morbidity associated with revision surgeries in this fragile population [34].

Implant considerations should also be mentioned. All augmented cases in our series used a helical blade with CA, whereas the conventional group included both blade and screw designs. Mitsuzawa et al. compared cement augmentation through a perforated helical blade with a perforated screw and found no significant differences in clinical or radiographic outcomes [35]. The two techniques provided effective mechanical stability along with similar pain relief and rehabilitation profiles. This is consistent with their earlier findings regarding cement distribution patterns with TFNA helical blades [18]. Other studies have similarly demonstrated that cement augmentation is effective regardless of the specific implant design used, as confirmed in a meta-analysis [17].

While CA shows promise in enhancing implant stability, concerns about cement-related complications remain. In a recent retrospective cohort study, Aguado et al. observed low rates of cement-related complications, supporting the safety profile of CA in older patients undergoing proximal femoral fracture fixation [36]. Most leakages are asymptomatic, but symptomatic cases can present with pain, restricted mobility, or mechanical complications. Thermal necrosis is a recognized complication of PMMA cement polymerization, as local temperatures can exceed 70 °C at the bone–cement interface, posing a significant risk of osteocyte damage, particularly in older patients with compromised bone quality [37]. Bone Cement Implantation Syndrome (BCIS), a potentially life-threatening complication of cemented arthroplasty and characterized by hypoxia, hypotension, and possible cardiac arrest, occurs in approximately 28–37% of patients undergoing cemented hip hemiarthroplasty, with severe BCIS reported in 5–7% of cases [38]. Recent developments in composite bone cements, such as PMMA combined with tricalcium silicate, have

demonstrated up to a 30% reduction in exothermic temperature, potentially lowering the risk of thermal necrosis without compromising mechanical properties [39].

Our study has several limitations. First, the retrospective design introduces inherent biases. Although we attempted to control for confounding with propensity matching, unmeasured variables could have influenced outcomes. Second, and most critically, our study was severely underpowered to detect differences in the primary outcome. With only 84 matched patients and a single cut-out event, the observed difference of 0% versus 1.8% cannot be interpreted as evidence of equivalence or superiority. Detecting a significant difference would require substantially larger sample sizes, representing a major constraint in drawing definitive conclusions about cement augmentation effectiveness. Third, the heterogeneity of implants in the conventional group is a confounder, as implant design differences could affect outcomes independent of cement. Finally, although our mean follow-up period of 19–23 weeks encompasses the period when most cut-out complications typically occur based on current literatures [40, 41], longer-term follow-up would strengthen our conclusions regarding the durability of cement augmentation and capture any late mechanical failures. Nonetheless, our study benefits from a matched cohort design, radiographic confirmation of technical equivalence, and real-world applicability in a consecutive older population, supporting its relevance to routine orthopedic decision-making regarding cement augmentation. Future prospective randomized controlled trials with adequate statistical power will be essential to definitively establish the efficacy of cement augmentation, with our observed event rates suggesting that approximately 1,500-2,000 patients would be needed to detect significant differences in mechanical failure rates.

Conclusions

This retrospective study found no significant differences in mechanical or clinical outcomes between cement-augmented and conventional cephalomedullary nailing for trochanteric fractures. The augmented group showed no cut-out events while the conventional group had one case (1.8%), though the limited sample size precludes definitive statistical conclusions regarding this difference. The absence of cement-related complications and comparable 1-year mortality rates (25.0% vs. 19.6%, $p = 0.78$) in our series suggest the technique may be safe when properly performed, though larger studies are needed to confirm these findings. Our preliminary data indicate that cement augmentation may be an option for selected patients, particularly those with severe osteoporosis or unstable fractures. Prospective randomized trials with adequate sample sizes and longer follow-up are required to establish the role of cement augmentation in managing osteoporotic trochanteric fractures.

Abbreviations

AP	Anteroposterior
ASA	American Society of Anesthesiologists
BCIS	Bone Cement Implantation Syndrom
BMI	Body Mass Index
CA	Cement Augmentation
Cal-TAD	Calcar-referenced Tip Apex Distance
CCI	Charlson Comorbidity Index
EQ-5D	EuroQol 5-Dimension
HHS	Harris Hip Score
IRB	Institutional Review Board
PFNA	Proximal Femoral Nail Antirotation
PMMA	Polymethylmethacrylate
PROMs	Patient-Reported Outcome Measures
PSM	Propensity Score Matching
TAD	Tip Apex Distance
TFNA	Trochanteric Fixation Nail Advanced

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12891-025-09249-9.

Supplementary Material 1: Supplementary Table 1. Comparison of Fracture Type, Implant Used, and Postoperative Reduction Assessment between the Two Groups before Propensity Score Matching.

Supplementary Material 2: Supplementary Table 2. Mechanical and Functional Outcomes of Cement-Augmented vs. Non-Augmented Cephalomedullary Nailing Groups before Propensity Score Matching.

Acknowledgements

None.

Authors' contributions

J.Y.P (Jun Young Park): Conceptualization, Methodology, Supervision, Writing – original draftT.K.K (Tae Kang Kim): Data curation, Formal analysis, VisualizationB.W.C (Byung Woo Cho): Data curation, ValidationH.M.K (Hyuck Min Kwon): Investigation, Formal analysisK.K.P (Kwan Kyu Park): Writing – review & editingW.S.L (Woo-Suk Lee): Supervision, Project administration, Writing – review & editing.

Funding

This study was supported by a faculty research grant of Yonsei University College of Medicine (6-2023-0151).

Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical approval and consent to participate

This study was approved by the Institutional Review Board (IRB) of Yongin Severance Hospital (9-2025-0048) and was conducted in accordance with the ethical principles of the Declaration of Helsinki and Good Clinical Practice guidelines. The requirement for informed consent was waived by the IRB due to the retrospective nature of this study. This research involved analysis of existing medical records and data, and posed minimal risk to participants. Patient anonymity and confidentiality were strictly maintained throughout the study.

Consent for publication

Individual consent for publication was waived by the IRB (9-2025-0048) due to the retrospective nature of the study and complete anonymization of all patient data and images.

Competing interests
The authors declare no competing interests.

Author details
[1]Department of Orthopaedic Surgery, Yongin Severance Hospital, Yonsei University College of Medicine, 363 Dongbaekjukjeon-daero, Giheung-gu, Yongin-si, Gyeonggi-do 16995, Republic of Korea
[2]Yonsei University Wonju College of Medicine, Wonju, Gangwon-do, Republic of Korea
[3]Department of Orthopaedic Surgery, Gangnam Severance Hospital, Yonsei University College of Medicine, Seoul, Republic of Korea
[4]Department of Orthopaedic Surgery, Severance Hospital, Yonsei University College of Medicine, Seoul, Republic of Korea

Received: 15 July 2025 / Accepted: 1 October 2025
Published online: 29 October 2025

References

1. Kim JW, Yoo JI, Kim JT, Choy WS, Cha Y. Clinical and radiological characteristics of lesser trochanter splitting irreducible intertrochanteric fractures. Clin Orthop Surg. 2023;15(4):560–6. https://doi.org/10.4055/cios22325.
2. Liau ZQG, Thirukumaran K, Sim SI, Pang AS. Surgical fixation of hip fractures- a novel technique for pre-operative planning. J Orthop Surg Res. 2025;20(1):391. https://doi.org/10.1186/s13018-025-05803-2.
3. Ryu HG, Shin DW, Han BS, Kim SM. Risk factors associated with fixation failure in intertrochanteric fracture treated with cephalomedullary nail. Hip Pelvis. 2023;35(3):193–9. https://doi.org/10.5371/hp.2023.35.3.193.
4. Huang J, Lin L, Lyu J, Fang X, Zhang W. Hip arthroplasty following failure of internal fixation in intertrochanteric femoral fractures: classification decision-making for femoral stem selection and clinical validation. J Orthop Surg Res. 2024;19(1):671. https://doi.org/10.1186/s13018-024-05136-6.
5. Ciufo DJ, Zaruta DA, Lipof JS, Judd KT, Gorczyca JT, Ketz JP. Risk factors associated with cephalomedullary nail cutout in the treatment of trochanteric hip fractures. J Orthop Trauma. 2017;31(11):583–8. https://doi.org/10.1097/bot.0000000000000961.
6. Ibrahim I, Appleton PT, Wixted JJ, DeAngelis JP, Rodriguez EK. Implant cut-out following cephalomedullary nailing of intertrochanteric femur fractures: are helical blades to blame? Injury. 2019;50(4):926–30. https://doi.org/10.1016/j.injury.2019.02.015.
7. Goodnough LH, Wadhwa H, Tigchelaar SS, DeBaun MR, Chen MJ, Graves ML, Gardner MJ. Indications for cement augmentation in fixation of geriatric intertrochanteric femur fractures: a systematic review of evidence. Arch Orthop Trauma Surg. 2022;142(10):2533–44. https://doi.org/10.1007/s00402-021-03872-6.
8. Mansour J, Zalaquett Z, Tarchichi J, Estephan M, Otayek J, Daher M. Safety of Cement-augmented femoral cephalomedullary nails: A Meta-analysis and systematic review. Hip Pelvis. 2025;37(1):17–25. https://doi.org/10.5371/hp.2025.37.1.17.
9. Sermon A, Zderic I, Khatchadourian R, Scherrer S, Knobe M, Stoffel K, Gueorguiev B. Bone cement augmentation of femoral nail head elements increases their cut-out resistance in poor bone quality- A Biomechanical study. J Biomech. 2021;118:110301. https://doi.org/10.1016/j.jbiomech.2021.110301.
10. Zheng L, Chen X, Zheng Y, He X, Wu J, Lin Z. Cement augmentation of the proximal femoral nail antirotation for the treatment of two intertrochanteric fractures - a comparative finite element study. BMC Musculoskelet Disord. 2021;22(1):1010. https://doi.org/10.1186/s12891-021-04878-2.
11. Dall'Oca C, Maluta T, Moscolo A, Lavini F, Bartolozzi P. Cement augmentation of intertrochanteric fractures stabilised with intramedullary nailing. Injury. 2010;41(11):1150–5. https://doi.org/10.1016/j.injury.2010.09.026.
12. Ni XH, Zhu XY, Zhang ZY, Zhang L, Ren LB, Wu JS, Wang LJ, Zhao QM, Zhang F. Clinical effect of cement-enhanced APFN in the treatment of elderly osteoporotic intertrochanteric fractures. Eur Rev Med Pharmacol Sci. 2022;26(11):3872–7. https://doi.org/10.26355/eurrev_202206_28954.
13. Bianco JM, Whitsell NW, McCormack TJ, Lais RL, Dart BR, Scott BR, Zackula RE, Corrigan CM. Influence of bone cement augmentation on complications in cephalomedullary nail fixation of geriatric intertrochanteric hip fractures. Kans J Med. 2024;17(3):57–60. https://doi.org/10.17161/kjm.vol17.21608.
14. Schneider F, Oettle C, Runer A, Wagner M, Arora R, Lindtner RA. Retrospective evaluation of radiological and clinical outcomes after surgical treatment of proximal femoral fractures utilizing PFNA and PFNA augmented. Arch Orthop Trauma Surg. 2024;144(6):2603–8. https://doi.org/10.1007/s00402-024-05349-8.
15. Kammerlander C, Hem ES, Klopfer T, Gebhard F, Sermon A, Dietrich M, Bach O, Weil Y, Babst R, Blauth M. Cement augmentation of the proximal femoral nail antirotation (PFNA) - A multicentre randomized controlled trial. Injury. 2018;49(8):1436–44. https://doi.org/10.1016/j.injury.2018.04.022.
16. Mochizuki Y, Yamamoto N, Fujii T, Tomita Y. Effectiveness of cement augmentation on early postoperative mobility in patients treated for trochanteric fractures with cephalomedullary nailing: A prospective cohort study. J Pers Med. 2022;12(9). https://doi.org/10.3390/jpm12091392.
17. Rompen IF, Knobe M, Link BC, Beeres FJP, Baumgaertner R, Diwersi N, Migliorini F, Nebelung S, Babst R, van de Wall BJM. Cement augmentation for trochanteric femur fractures: A meta-analysis of randomized clinical trials and observational studies. PLoS ONE. 2021;16(6):e0251894. https://doi.org/10.1371/journal.pone.0251894.
18. Mitsuzawa S, Matsuda S. Cement distribution and initial fixability of trochanteric fixation nail advanced (TFNA) helical blades. Injury. 2022;53(3):1184–9. https://doi.org/10.1016/j.injury.2021.10.028.
19. Esper GW, Fisher ND, Anil U, Ganta A, Konda SR, Egol KA. Hip Pelvis. 2023;35(3):175–82. https://doi.org/10.5371/hp.2023.35.3.175. Cut-Through versus Cut-Out: No Easy Way to Predict How Single Lag Screw Design Cephalomedullary Nails Used for Intertrochanteric Hip Fractures Will Fail?.
20. Gilat R, Lubovsky O, Atoun E, Debi R, Cohen O, Weil YA. Proximal femoral shortening after cephalomedullary nail insertion for intertrochanteric fractures. J Orthop Trauma. 2017;31(6):311–5. https://doi.org/10.1097/bot.0000000000000835.
21. Tsukada S, Okumura G, Matsueda M. Postoperative stability on lateral radiographs in the surgical treatment of Pertrochanteric hip fractures. Arch Orthop Trauma Surg. 2012;132(6):839–46. https://doi.org/10.1007/s00402-012-1484-9.
22. Choo S-K, Oh H-K, Kim Y-C, Lee D-B. Excessive sliding of compression hip screw for the treatment of intertrochanteric fracture in elderly. Hip Pelvis. 2007;19(3):190–6. https://doi.org/10.5371/jkhs.2007.19.3.190.
23. Reis JPG, Lopes AL, Branco RJ, Sapage R, Sousa RA, Sousa D. Trochanteric fractures: Tip-Apex distance, Calcar Tip-Apex distance, and Chang criteria-a multiple variable analysis. Arch Orthop Trauma Surg. 2023;143(12):7035–41. https://doi.org/10.1007/s00402-023-05018-2.
24. Baumgaertner MR, Curtin SL, Lindskog DM, Keggi JM. The value of the tip-apex distance in predicting failure of fixation of peritrochanteric fractures of the hip. J Bone Joint Surg Am. 1995;77(7):1058–64. https://doi.org/10.2106/00004623-199507000-00012.
25. Cleveland M, Bosworth DM, Thompson FR, Wilson HJ Jr., Ishizuka T. A ten-year analysis of intertrochanteric fractures of the femur. J Bone Joint Surg Am. 1959;41(8):1399– 408.
26. Chang SM, Zhang YQ, Ma Z, Li Q, Dargel J, Eysel P. Fracture reduction with positive medial cortical support: a key element in stability reconstruction for the unstable Pertrochanteric hip fractures. Arch Orthop Trauma Surg. 2015;135(6):811–8. https://doi.org/10.1007/s00402-015-2206-x.
27. Liu Y, Zheng L, Li S, Zhang Z, Lin Z, Ma W. Finite element study on the micromechanics of cement-augmented proximal femoral nail anti-rotation (PFNA) for intertrochanteric fracture treatment. Sci Rep. 2024;14(1):10322. https://doi.org/10.1038/s41598-024-61122-2.
28. Bungartz M, Matziolis G, Layher F, Horbert V, Maslaris A, Brinkmann O. Biodegradable cement augmentation of gamma nail osteosynthesis reduces migration in Pertrochanteric fractures, a Biomechanical in vitro study. Clin Biomech (Bristol). 2021;84:105327. https://doi.org/10.1016/j.clinbiomech.2021.105327.
29. Olarte Salazar CM, Burgos EJ, Sánchez D, Libos A, Arango F, Triana M, Salavarrieta J, Pesantez R. Outcomes of cement augmentation in fragility trochanteric hip fractures - A multicenter randomized controlled trial follow-up. Injury. 2023;54(Suppl 6):110776. https://doi.org/10.1016/j.injury.2023.05.007.
30. Kulachote N, Sa-Ngasoongsong P, Sirisreetreerux N, Chulsomlee K, Thamyongkit S, Wongsak S. Predicting factors for return to prefracture ambulatory level in high surgical risk elderly patients sustained intertrochanteric fracture and treated with proximal femoral nail antirotation (PFNA) with and without cement augmentation. Geriatr Orthop Surg Rehabil. 2020;11:2151459320912121. https://doi.org/10.1177/2151459320912121.
31. Yan X, Huang J, Chen X, Lin M. Association between increased systemic immune-inflammation index and postoperative delirium in older intertrochanteric fracture patients. J Orthop Surg Res. 2024;19(1):219. https://doi.org/10.1186/s13018-024-04699-8.

32. Chen Y, Guo Y, Tong G, He Y, Zhang R, Liu Q. Combined nutritional status and activities of daily living disability is associated with one-year mortality after hip fracture surgery for geriatric patients: a retrospective cohort study. Aging Clin Exp Res. 2024;36(1):127. https://doi.org/10.1007/s40520-024-02786-8.
33. Joeris A, Kabiri M, Galvain T, Vanderkarr M, Holy CE, Plaza JQ, Tien S, Schneller J, Kammerlander C. Cost-Effectiveness of cement augmentation versus no augmentation for the fixation of unstable trochanteric fractures. J Bone Joint Surg Am. 2022;104(22):2026–34. https://doi.org/10.2106/jbjs.21.01516.
34. Huyke-Hernández FA, Only AJ, Sorich M, Onizuka N, Switzer JA, Cunningham BP. Outcomes after revision fixation with cement augmentation for failed intertrochanteric fracture fixation in older adult patients. Geriatr Orthop Surg Rehabil. 2022;13:21514593221135480. https://doi.org/10.1177/21514593221135480.
35. Mitsuzawa S, Nakamata T, Mitamura S, Yasuda T, Matsuda S. Which head element is more effective for cement augmentation of TFNA? Helical blade versus lag screw. BMC Musculoskelet Disord. 2023;24(1):544. https://doi.org/10.1186/s12891-023-06671-9.
36. Aguado HJ, País-Ortega S, García-Virto V, Bodas-Gallego P, Álvarez-Ramos A, Ganso A, Plata-García M, Macho-Mier M, Rodríguez-García E, García-Medrano B, et al. Proximal femoral fractures in the elderly. Does cement augmentation decrease mechanical failures and increase function? A retrospective cohort study. Injury. 2024;55(Suppl 5):111673. https://doi.org/10.1016/j.injury.2024.111673.
37. Szoradi GT, Feier AM, Zuh SG, Russu OM, Pop TS. Polymethyl methacrylate bone cement polymerization induced thermal necrosis at the cement–Bone interface: A narrative review. Appl Sci. 2024;14(24):11651.
38. Al-Husinat Li, Jouryyeh B, Al Sharie S, Al Modanat Z, Jurieh A, Al Hseinat L, Varrassi G. Bone cement and its anesthetic complications: A narrative review. J Clin Med. 2023;12(6):2105.
39. Wei Y, Baskaran N, Wang HY, Su YC, Nabilla SC, Chung RJ. Study of polymethylmethacrylate/tricalcium silicate composite cement for orthopedic application. Biomed J. 2023;46(3):100540. https://doi.org/10.1016/j.bj.2022.05.005.
40. Bojan AJ, Beimel C, Taglang G, Collin D, Ekholm C, Jönsson A. Critical factors in cut-out complication after gamma nail treatment of proximal femoral fractures. BMC Musculoskelet Disord. 2013;14:1. https://doi.org/10.1186/1471-2474-14-1.
41. Hernández-Pascual C, Santos-Sánchez J, García-González JM, Silva-Viamonte CF, Pablos-Hernández C, Ramos-Pascua L, Mirón-Canelo JA. Long-term outcomes of distal locking in extracapsular fractures treated with trochanteric Gamma3 nails. J Orthop Traumatol. 2021;22(1):48. https://doi.org/10.1186/s10195-021-00609-4.

Publisher's Note