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# Increased risk of periprosthetic fracture associated with decreased aseptic loosening in C-stem compared with the Charnley Elite Plus in primary total hip arthroplasty: a minimum 10-year follow-up study

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## Abstract

**Background** The Charnley stem design has evolved, with notable modifications from the 6th generation (Elite Plus) to the 7th generation (C-stem), potentially affecting load transmission and clinical outcomes. This study aimed to compare the clinical, radiological, and survival outcomes between the Elite Plus and C-stem.

**Methods** A retrospective review was conducted on 131 primary total hip arthroplasties in 115 patients. A minimum 10-year follow-up was completed for 89 hips (78 patients) with the Elite Plus and 42 hips (37 patients) with the C-stem, with mean follow-ups of 15.8 and 11.7 years, respectively.

**Results** The surgical procedures were hybrid arthroplasty with lateral and posterior approach for the Elite Plus group and cement arthroplasty with anterior and lateral approach for the C-stem group. In the Elite Plus group, five patients experienced dislocations and three developed aseptic loosening (AL); in the C-stem group, three cases of periprosthetic fracture (PPF) occurred. Four cases in the Elite Plus and two cases in the C-stem group required revision arthroplasty. The reasons for revision surgery were AL of the acetabular component in two cases and femoral AL in two cases in the Elite Plus group and PPF in two cases in the C-stem group. Radiolucent lines were significantly more frequent with the Elite Plus (33.7%) than with the C-stem (11.9%). After excluding three patients with extreme subsidence (≥ 3 mm) in the Elite Plus group, the average stem subsidence was found to be significantly larger with the C-stem (0.88 mm) than with the Elite Plus (0.17 mm) ($p < 0.001$, Mann–Whitney U test). With revision surgery due to any reason as the endpoint, the 10-year survival rates were 96.6% for the Elite Plus and 95.2% for the C-stem, showing no significant difference. However, survival rates differed significantly with PPF as the endpoint (100% for the Elite Plus vs. 92.9% for the C-stem, $p = 0.01$).

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**Conclusions** Both stems achieved satisfactory 10-year outcomes. The Elite Plus stem showed more frequent loosening and radiolucent lines, whereas the C-stem demonstrated a stable cement-bone interface but had several PPF cases. Design differences likely contributed to these variations in outcomes.

**Keywords** Charnley stem, Elite plus, C-stem, Taper-slip, Composite-beam

## Background

The Charnley low-friction arthroplasty (DePuy Synthes, USA) is considered one of the most significant innovations of the 20th century [1–3]. The stem design for Charnley arthroplasty has undergone several modifications. The 1st -generation Charnley stem, developed in the early 1960s, featured a polished surface, minimal collar, and a single-taper design in the mediolateral dimension [4]. In the first flatback stem, Weber and Charnley reported a notable incidence of subsidence with transverse cement fractures near the stem tip [5]. Although patients with subsidence were mostly asymptomatic, the Charnley stem design was subsequently modified to include a dorsal flange and a textured surface [5]. In later generations of the Charnley stem with a dorsal flange, transverse cement fractures near the distal portion and subsidence were eliminated [6]. Nevertheless, the rate of aseptic loosening (AL) in this stem was reportedly higher than that in the 1st -generation Charnley stem [7]. Shen suggested that this seemingly minor modification altered the stem's behavior from a taper-slip to a composite-beam concept, potentially impacting long-term clinical outcomes [8].

The 6th -generation Charnley stem (Elite Plus) retained the "composite-beam" concept, featuring a proximal flange, single taper, and textured surface (Ra: 0.66–1.21 μm). The stem material remained high-nitrogen stainless steel (Ortron 90), although the stem diameter was reduced, and a distal centralizer was introduced to improve cement mantle uniformity. Reports on the Elite Plus stem have been conflicting, with some studies demonstrating unsatisfactory outcomes and others showing successful results [9–19].

The 7th -generation Charnley stem (C-stem) introduced a triple-taper geometry, polished surface (Ra: 0.025–0.03 μm), and collarless design. This stem was engineered to subside within the cement mantle, with the goal of creating a favorable load distribution at the cement-bone interface and mitigating the stress shielding observed with composite-beam stems, such as the flanged Charnley stem [20]. The C-stem design marked a shift from the composite-beam concept used in previous designs back to the taper-slip concept of the 1st -generation Charnley stem.

The current study aimed to compare clinical (periprosthetic fracture [PPF] and need for revision surgery) and radiographic (subsidence, radiolucent lines, and AL) outcomes between the Elite Plus and C-stem, which were potentially affected by alterations in the stems' design and behavior.

## Methods

The current study was a retrospective consecutive study conducted on primary total hip replacements with the femoral component of the Charnley Elite Plus and C-stem. A total of 798 primary total hip replacements were performed at Matsudo City General Hospital (Chiba, Japan) from August 1996 to June 2009. The Charnley Elite Plus and C-stem were implanted in 137 hips from August 1996 to April 2004 and in 70 hips from March 2005 to June 2009, respectively (Fig. 1). The sample size was calculated when no prior study was carried out.

The indication for using a femoral component with cement during the study period was relatively poor femoral bone quality (femoral cortical index $<$ 50%) in active adult patients. During the same period, cementless stems were implanted in patients with good femoral bone quality (femoral cortical index $>$ 50%) and other types of cemented stems owing to the use of ceramic femoral head in active young patients. A minimum 10-year follow-up was completed for 89 hips (78 patients) with the Elite Plus and 42 hips (37 patients) with the C-stem. The research protocol was approved by the Institutional Review Board of Matsudo City General Hospital (No. R5-3), in compliance with the principles of the Declaration of Helsinki and its amendments. Information about the study, including options for patients to refuse participation, was provided on the hospital website (opt-out method).

### Patient characteristics

The mean age at surgery was 64.8 years (range, 42–87) in the Elite Plus group and 61.5 years (range, 31–83) in the C-stem group, with no difference in patient age ($p = 0.161$, Mann–Whitney U test; 95% confidence interval [CI]: -1.37 to 8.04). The Elite Plus group included 10 men and 68 women, whereas the C-stem group comprised 9 men and 28 women, with no significant difference in sex ($p = 0.177$, Fisher's exact test). The primary conditions requiring hip replacement were osteoarthritis (74 with the Elite Plus and 13 with the C-stem), rheumatoid arthritis (2 with the Elite Plus and 12 with the C-stem), avascular necrosis of the femoral head (12 with the Elite Plus and 15 with the C-stem), and rapidly destructive coxarthrosis (1 with the Elite Plus and 2 with

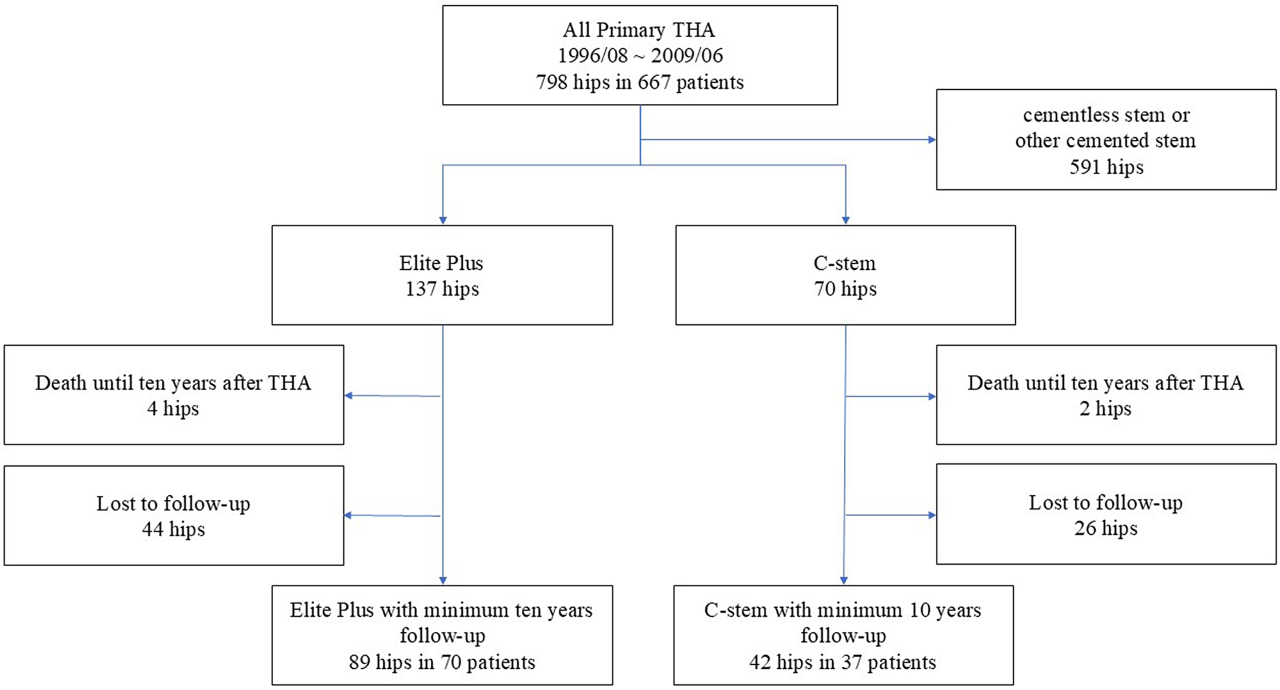


**Fig. 1** A Flow chart illustrating the inclusion criteria

the C-stem). The primary disorder significantly differed between the two groups ($p < 0.001$, Fisher's exact test).

## Surgical procedures

Elite Plus implantation was performed using an anterolateral (73 hips) or posterolateral (16 hips) approach. Hybrid total hip replacement (cementless cup) was performed in 83 hips, whereas cemented total hip replacement (cement cup) was carried out in 6 hips. The acetabular components used were Charnley (DePuy Synthes) in 4 cases, Elite Plus (DePuy Synthes) in 2 cases, and Duraloc (DePuy Synthes) in 83 cases. The bone cements used were Endurance (DePuy Synthes) in 67 cases, Simplex (Stryker Corp., USA) in 10 cases, and unknown in 12 cases.

C-stem implantation was performed using a direct anterior (32 hips) or direct lateral (10 hips) approach. Hybrid total hip replacement (cementless cup) was conducted in only one hip, whereas cemented total hip replacement (cement cup) was performed in 41 hips. The acetabular components used were Charnley in 10 cases, Elite Plus in 30 cases, FL-CP (Kyocera Corp., Japan) in 1 case, and Trident (Stryker Corp.) in 1 case. The bone cement used was Simplex in 41 cases and unknown in 1 case.

The femoral head diameters were 22 mm in 63 and 10 hips in the Elite Plus and C-stem groups, respectively, and 26 mm in 26 and 32 hips in the Elite Plus and C-stem groups, respectively. The surgical procedures, including the approach, cup, cement type, and femoral head size, were significantly different between the two groups (all $p < 0.01$, Fisher's exact test).

All primary total hip replacements were performed using 3rd -generation cementing techniques, including vacuum mixing and the use of a cementing gun for retrograde filling and a proximal femoral pressurizer.

## Assessment

Clinical and radiological evaluations were performed preoperatively, at 3 weeks (baseline radiograph), and annually with a minimum 10-year follow-up. At each follow-up visit, operating surgeons performed physical examinations, and functional outcomes were evaluated using the Japanese Orthopedic Association (JOA) hip score (maximum score = 100) [21].

Anteroposterior radiographs of the pelvis in the supine position and frog-leg lateral radiographs were obtained. Cementing quality was assessed using Barrack's classification [22]. Stem subsidence was measured on magnified images calibrated with the known size of the femoral head. Radiological landmarks used included the greater trochanter, proximolateral cement mantle, and shoulder of the prosthesis, as described by Fowler et al. [23]. Radiolucent lines were evaluated according to definitions by Gruen et al. [24] and Johnston et al. [25], with their presence assessed following the criteria of Kobayashi et al. [26]. Radiological loosening was classified according to Harris et al. [27] and Pacheco et al. [28], with stem migration, subsidence > 3 mm, or cement fracture considered indicative of loosening.

Stem alignment was assessed on 3-week postoperative hip radiographs. Coronal alignment was measured from the anteroposterior view, with positive and negative values indicating varus and valgus stem alignments, respectively. Sagittal alignment was assessed on lateral radiographs, with positive and negative angles indicating extension and flexion positions, respectively. Postoperative complications, including prosthetic joint infection, dislocation, PPF, AL, and revision surgery, were also assessed.

### Statistical analyses

Statistical analyses were performed using R statistical software (https://www.r-project.org, R Foundation for Statistical Computing, Vienna, Austria). Statistical results were cross-checked using SPSS software version 20.0.2.0 (IBM Corp., Armonk, NY, USA). The Kaplan–Meier method was employed to analyze survival rates, with AL, revision surgery for AL, PPF, and revision surgery for any other reason as the endpoints. The log-rank test, Fisher's exact test, and Mann–Whitney U test with 95% CI were used for comparisons between the Elite Plus and C-stem groups. A two-sided *p*-value of $< 0.05$ was considered to indicate statistical significance. Bonferroni correction was applied when performing Fisher's exact test on three or more categories.

## Results

The demographic characteristics are summarized in Table 1, and postoperative outcomes are provided in Table 2. The mean follow-up durations were 15.6 years for the Elite Plus group and 11.7 years for the C-stem

**Table 1** Demographic characteristics of patients in the elite plus and C-stem groups

| | | Charnley Elite Plus | C-stem | *p*-value | 95% CI |
|---|---|---|---|---|---|
| Patients | | 78 | 37 | - | |
| Hips | | 89 | 42 | - | |
| Age, average | | 64.8 ± 9.5 | 61.5 ± 13.8 | 0.161* | -1.37 to 8.04 |
| | Max | 87 | 83 | - | |
| | Min | 42 | 31 | - | |
| Follow-up, average | | 15.6 ± 3.2 | 11.7 ± 1.3 | < 0.001* | 3.16 to 4.72 |
| | | Charnley Elite Plus | C-stem | *p*-value | 95% CI |
| Sex | | | | 0.177** | |
| | Male | 10 (12.8%) | 9 (24.3%) | | |
| | Female | 68 (87.2%) | 28 (75.7%) | | |
| Primary disorder | | | | < 0.001* | |
| | Osteoarthritis | 74 (83.1%) | 13 (31.0%) | | |
| | Rheumatoid arthritis | 2 (2.2%) | 12 (28.6%) | | |
| | Avascular necrosis of the femoral head | 12 (13.5%) | 15 (35.7%) | | |
| | Rapidly destructive coxarthrosis | 1 (1.1%) | 2 (4.8%) | | |
| Surgical approach | | | | < 0.001* | |
| | Anterolateral | 73 (82.0%) | 10 (23.8%) | | |
| | Posterolateral | 16 (18.0%) | 0 | | |
| | Direct anterior | 0 | 32 (76.2%) | | |
| Cup fixation | | | | < 0.001* | |
| | Cementless | 83 (93.3%) | 1 (2.4%) | | |
| | Cement | 6 (6.7%) | 41 (97.6%) | | |
| Cup | | | | < 0.001* | |
| | Charnley | 4 (4.5%) | 10 (23.8%) | | |
| | Elite Plus | 2 (2.2%) | 30 (71.4%) | | |
| | FL-CP | 0 | 1 (2.4%) | | |
| | Duraloc | 83 (93.3%) | 0 | | |
| | Trident | 0 | 1 (2.4%) | | |
| Cement | | | | 0.007* | |
| | Endurance | 67 (75.3%) | 41 (97.6%) | | |
| | Simplex | 10 (11.2%) | 0 | | |
| | Unknown | 12 (13.5%) | 1 (2.4%) | | |
| Femoral head | | | | < 0.001* | |
| | 22 mm | 63 (70.8%) | 10 (23.8%) | | |
| | 26 mm | 26 (29.2%) | 32 (76.2%) | | |

CI, confidence interval. *Mann–Whitney U test, **Fisher's exact test

**Table 2** Comparison of postoperative outcomes between the elite plus and C-stem groups

| | | Charnley Elite Plus | C-stem | *p*-value | 95% CI |
|---|---|---|---|---|---|
| | | **89 hips** | **42 hips** | | |
| JOA hip score | | | | | |
| | Preoperative | 40.0 ± 10.6 | 37.2 ± 8.1 | 0.110 | -0.65 to 6.29 |
| | Postoperative | 84.7 ± 6.5 | 84.6 ± 7.8 | 0.931 | -2.70 to 2.94 |
| Cementing grade | | | | 0.786 | |
| | A | 75 (84.3%) | 36 (85.7%) | | |
| | B | 13 (14.6%) | 6 (14.3%) | | |
| | C | 0 | 0 | | |
| | D | 0 | 0 | | |
| | Not applicable | 1 (1.1%) | 0 | | |
| Radiolucent line | | | | | |
| | Any zone | 30 (33.7%) | 5 (11.9%) | 0.008** | |
| | 1 | 19 (21.3%) | 1 (2.4%) | | |
| | 2 | 1 (1.1%) | 1 (2.4%) | | |
| | 3 | 1 (1.1%) | 0 | | |
| | 4 | 1 (1.1%) | 0 | | |
| | 5 | 1 (1.1%) | 0 | | |
| | 6 | 1 (1.1%) | 0 | | |
| | 7 | 10 (11.2%) | 0 | | |
| | 8 | 5 (5.6%) | 5 (11.9%) | | |
| | 9 | 0 | 0 | | |
| | 10 | 0 | 0 | | |
| | 11 | 0 | 0 | | |
| | 12 | 0 | 0 | | |
| | 13 | 1 (1.1%) | 0 | | |
| | 14 | 14 (15.7%) | 1 (2.4%) | | |
| Subsidence | Average (all hips) | 0.60 ± 3.0 | 0.88 ± 0.44 | 0.198* | -0.93 to 0.37 |
| | Average (excluding definite loosening cases) | 0.17 ± 0.42 | 0.88 ± 0.44 | < 0.001* | -0.87 to -0.54 |
| | 0 mm | 59 (66.3%) | 1 (2.4%) | | |
| | 0–3 mm | 27 (30.3%) | 41 (97.6%) | | |
| | < 3 mm (definite loosening) | 3 (3.4%) | 0 | | |
| Stem alignment | | | | | |
| | Coronal | | | | |
| | Mean angle (varus positive) | –0.37 ± 1.5 | 0.12 ± 1.5 | 0.089* | -1.04 to 0.08 |
| | Neutral | 84 (94.4%) | 39 (92.9%) | | |
| | Varus (> 3°) | 3 (3.4%) | 3 (7.1%) | | |
| | Valgus (> 3°) | 2 (2.2%) | 0 | | |
| | Sagittal | | | | |
| | Mean angle (extension positive) | 1.7 ± 1.7 | 1.6 ± 1.9 | 0.79* | -0.59 to 0.77 |
| | Neutral | 73 (82.0%) | 36 (85.7%) | | |
| | Extension (> 3°) | 16 (18.0%) | 5 (11.9%) | | |
| | Flex (> 3°) | 0 | 1 (2.4%) | | |
| Complications | | | | | |
| | Prosthetic joint infection | 0 | 0 | | |
| | Dislocation | 5 (5.6%) | 0 | 0.176** | |
| | PPF | 0 | 3 (7.1%) | 0.031** | |
| | AL | 3 (3.4%) | 0 | 0.551** | |
| Re-operation | | | | | |
| | Revision arthroplasty | 4 (4.5%) | 2 (4.8%) | | |
| | Stem loosening | 2 (2.2%) | 0 | | |
| | Acetabular component | 2 (2.2%) | 0 | | |

**Table 2** (continued)

| | Charnley Elite Plus | C-stem | *p*-value | 95% CI |
|---|---|---|---|---|
| | **89 hips** | **42 hips** | | |
| PPF | 0 | 2 (4.8%) | | |
| ORIF | 0 | 1 (2.4%) | | |

AL, aseptic loosening; JOA, Japanese Orthopedic Association; ORIF, open reduction and internal fixation; PPF, periprosthetic fracture

*Mann–Whitney U test, **Fisher's exact test

group, showing a significant difference ($p < 0.001$; 95% CI: 3.16–4.72).

Postoperative JOA scores significantly improved from 40 to 84.7 in the Elite Plus group ($p < 0.001$, Mann–Whitney U test; 95% CI: -4.65 to -3.31) and from 37.2 to 84.6 in the C-stem group ($p < 0.001$, Mann–Whitney U test; 95% CI: -6.39 to -4.03). Significant differences in neither preoperative JOA scores nor postoperative JOA scores were identified between the two groups ($p = 0.110$ for preoperative JOA scores and $p = 0.310$ for postoperative JOA scores, Mann–Whitney U test). Cementing quality was satisfactory, with Grade A achieved in 75 hips (84.3%) in the Elite Plus group and 36 hips (85.7%) in the C-stem group according to Barrack's classification. All remaining cases were classified as Grade B, exhibiting mild radiolucency; no cases were classified as Grade C or D. One postoperative radiograph in the Elite Plus group was lost, categorizing this case as "not applicable." The two groups exhibited no significant difference in cementing grade ($p = 0.786$, Fisher's exact test).

Radiolucent lines, defined as radiolucency bordered by areas of increased density, were more frequent in the Elite Plus group (33.7% of hips) than in the C-stem group (11.9%) across all zones ($p = 0.008$, Fisher's exact test). As previously mentioned above, the postoperative cementing grade according to Barrack's classification was satisfactory, and radiolucent lines were not seen on initial postoperative radiographs. All radiolucent lines developed at the annual follow-up. In both groups, radiolucent lines primarily appeared in the proximal femur (zones 1, 7, 8, and 14).

Extreme stem subsidence (≥3 mm) occurred in three patients in the Elite Plus group at 3.7, 7.5, and 10.0 years postoperatively during the annual follow-up, all of whom were subsequently diagnosed with definite loosening. After excluding these three patients, the average stem subsidence at the latest minimum 10-year follow-up postoperatively was found to be significantly higher in the C-stem group (0.88 mm) than in the Elite Plus group (0.17 mm) ($p < 0.001$, Mann–Whitney U test; 95% CI: -0.87 to -0.54).

Three cases of varus stem alignment exceeding 3° were noted in both Elite Plus and C-stem groups. No valgus alignment was observed in the Elite Plus group, whereas two cases were found in the C-stem group. Extension alignments were more frequent, with 16 cases in the Elite Plus group and 5 in the C-stem group; no flexion alignments were observed in the Elite Plus group, but there was one case in the C-stem group. Mann–Whitney U test analysis revealed no significant difference in coronal alignment between the two groups. ($p = 0.089$; 95% CI: -1.04 to 0.08).

In the Elite Plus group, five patients experienced dislocations, three patients had definite AL (Fig. 2), and four patients underwent revision surgery. Revision surgery was performed for dislocation in one case, stem AL in two cases, and acetabular component AL in one case. In the C-stem group, three patients developed PPF at 1 month, 4.37 years, and 4.72 years after surgery, respectively. Details of PPF cases are shown in Table 3. All three patients with PPF experienced minor trauma due to a fall (two patients) or from standing up from the floor (one patient). Revision surgery and osteosynthesis for PPF were performed in two patients (Fig. 3) and one patient, respectively.

With AL, revision surgery for AL, PPF, and revision surgery for any other reason as the endpoints, the 10-year survival rates were 97.7%, 97.7%, 100%, and 96.6% in the Elite Plus group and 100%, 100%, 92.9%, and 95.2% in the C-stem group, respectively (Figs. 4, 5, 6 and 7). With PPF as the endpoint, the log-rank test indicated a significant difference in survival between the groups ($p = 0.01$). In the Elite Plus group, the 20-year survival rates with AL and revision surgery for any other reason as the endpoints were 94.2% and 87.8%, respectively. With revision surgery for any other reason as the endpoint, the 10-year survival rates were 96.6% in the Elite Plus group and 95.2% in the C-stem group (Fig. 8), with no significant difference ($p = 0.70$, log-rank test).

## Discussion

The clinical outcomes of Elite Plus total hip arthroplasty (THA) have varied across studies (Table 4). While some studies report suboptimal results, others indicate favorable outcomes with the Charnley Elite Plus.

For example, Kim et al. [14] documented favorable clinical outcomes using conventional polyethylene acetabular cups and medium-to-high-viscosity bone cement, attributing success to modern cementing techniques, precise stem alignment, and relatively lower body weight in their Asian cohort. Similarly, with AL as the endpoint, Goto et al. [19] reported 10- and 15-year survival rates of 100%


**Fig. 2** A case of aseptic loosening (AL) with the Elite Plus stem. (**a**) Radiograph at 5 years after surgery. (**b**) Radiograph at 17 years after surgery showing a radiolucent line around the cement mantle and notable stem subsidence

**Table 3** Details of periprosthetic fracture cases

| Age at surgery | Sex | Primary disorder | Years from operation | Vancouver classification | Mechanism of injury | Treatment | Comorbidities |
|---|---|---|---|---|---|---|---|
| 60 | Male | OA | 0.10 | C | Fall | Revision arthroplasty | |
| 76 | Female | OA | 4.37 | B1 | Fall | Osteosynthesis | Steroid, bisphosphonate |
| 49 | Male | AN | 4.72 | B2 | Standing up from the floor | Revision arthroplasty | Hepatic cirrhosis, alcoholic neuropathy |

**Fig. 3** A case of periprosthetic femoral fracture (PPF) with the C-stem. (**a**) Radiograph immediately after surgery. (**b**) Radiograph at 4.9 years after surgery showing a Vancouver B2 fracture

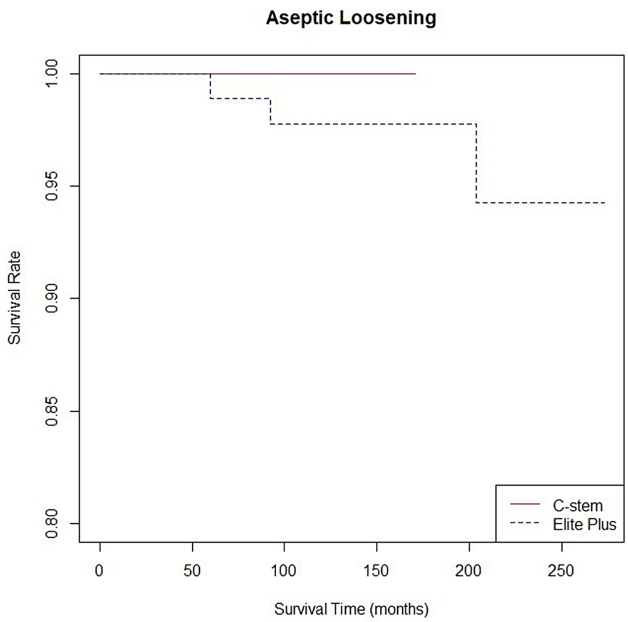


**Fig. 4** Kaplan–Meier survival rates for aseptic loosening (AL). The 10-year survival rates were 97.7% for the Elite Plus group and 100% for the C-stem group. The Elite Plus group had a 20-year survival rate of 94.2%

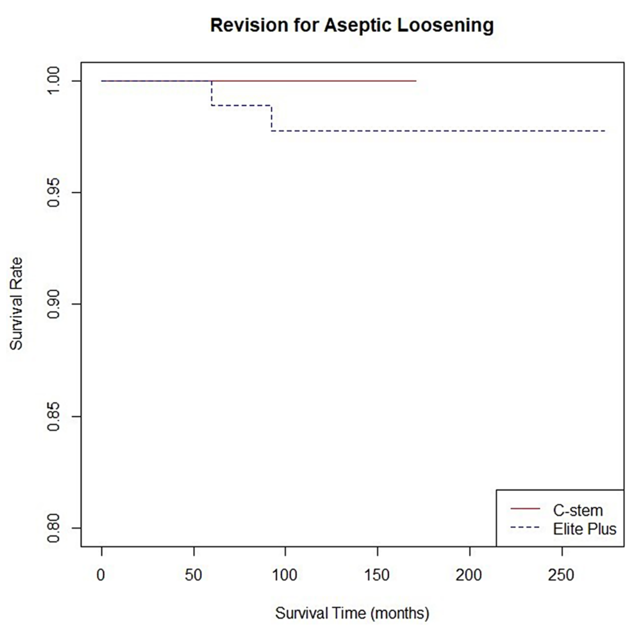


**Fig. 5** Kaplan–Meier survival rates for revision surgery due to aseptic loosening (AL). The 10-year survival rates were 97.7% for the Elite Plus group and 100% for the C-stem group

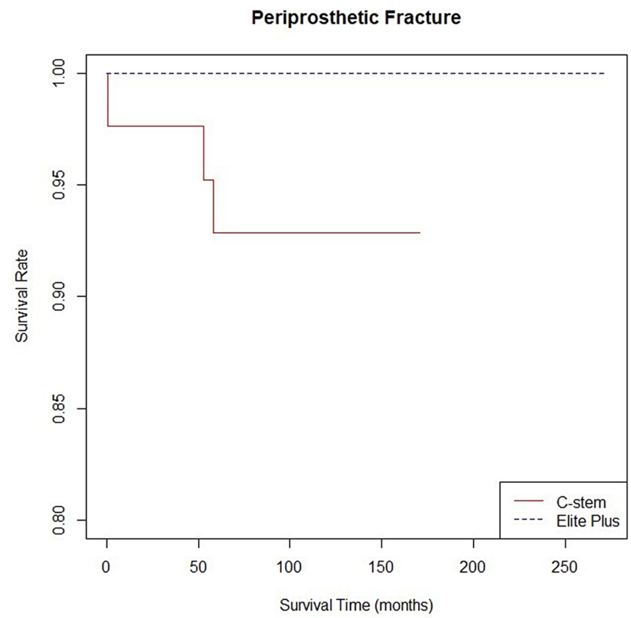


**Fig. 6** Kaplan–Meier survival rates for periprosthetic femoral fracture (PPF). The 10-year survival rates were 100% for the Elite Plus group and 92.9% for the C-stem group. The log-rank test showed a significant difference in survival with PPF as the endpoint ($p = 0.01$)

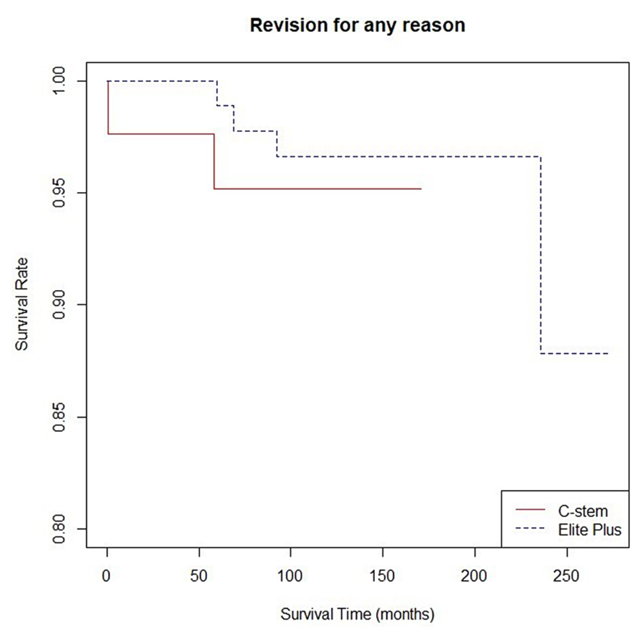


**Fig. 7** Kaplan–Meier survival rates with revision surgery for any reason. The 10-year survival rates were 96.6% for the Elite Plus group and 95.2% for the C-stem group, with the Elite Plus group achieving an 87.8% survival rate at 20 years

and 98.1%, respectively, in a Japanese population. Our findings align closely with these results, showing survival rates of 97.7% and 96.6% with revision surgery and AL as the endpoints, respectively.

Several factors may contribute to the variable performance of the Elite Plus. Studies have associated the use of low-viscosity cement with poorer outcomes [11, 16, 17], and concerns have been raised regarding Hylamer polyethylene [9, 18]. In a Nordic registry [29], 10-year survivorship rates above 90% were observed for several THA models, including the Charnley stem (94.1%) and the C-stem (95.8%). However, the Elite Plus showed a comparatively lower 10-year survival rate of 89.8%.

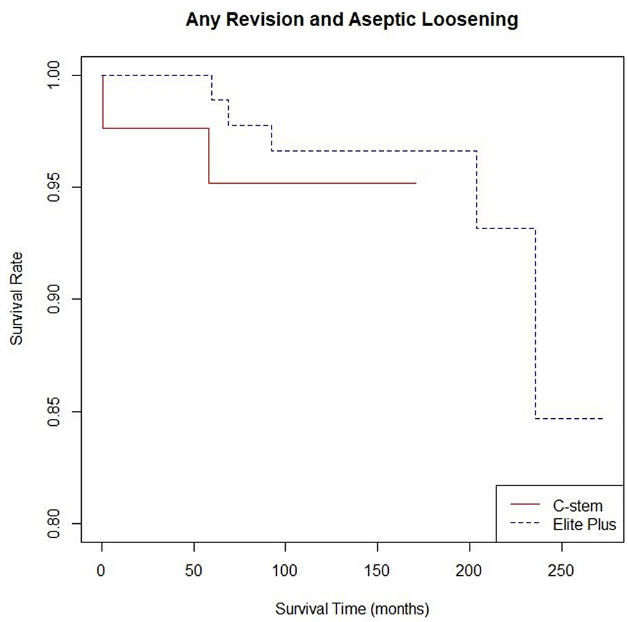


**Fig. 8** Kaplan–Meier survival rates with revision surgery for any reason and aseptic femoral loosening as endpoints. The 10-year survival rates were 96.6% for the Elite Plus group and 95.2% for the C-stem group. The Elite Plus group showed an 84.7% survival rate at 20 years

The Elite Plus design may have features that impact outcomes. For instance, the dorsal flange, intended to prevent distal stem migration within the cement mantle as part of the "composite-beam" concept, may have unintended consequences. Sangiorgio et al. [30] found that flanges increased both stem-cement interlock and bone-cement micromotion in an in vitro model. This could explain our finding of less subsidence in the Elite Plus group compared with the C-stem group. However, the higher incidence of radiolucent lines in the Elite Plus group (29%) compared with the C-stem group (5%) suggests increased bone-cement micromotion and a potential long-term risk of AL. In this study, different types of cement such as Endurance and Simplex were used; nevertheless, both types were medium-viscosity cement, not low-viscosity cement, which could affect poorer outcomes.

Rotational stability has also been a concern for Elite Plus. Hauptfleisch et al. [13] reported rapid posterior head migration and a high failure rate, with a 10-year survivorship rate of 59% when radiological loosening was considered a failure. Additionally, Alfaro-Adrián et al. [31] found that while the Charnley Elite and Exeter stems had different early migration patterns, 20% of Elite stems showed rapid posterior head migration, a pattern not observed in Exeter stems. These findings highlight concerns regarding rotational stability with the Elite Plus.

Von Schewelov et al. [17] observed increased migration in the Elite Plus compared to the Charnley stem in a clinical and radiographic analysis of 114 patients over an average of 7 years. They suggested that the Elite Plus's higher migration rate might be related to its slender design and sensitivity to implantation technique and cement choice, recommending closer follow-up in patients with lower radiographic scores, particularly when low-viscosity cement is used.

The surface finish differs between the Elite Plus, which features a textured surface finish (Ra: 0.66–1.21 μm), and C-stem, which offers a polished surface finish (Ra: 0.025–0.03 μm). A systematic review of cemented femoral components with long-term follow-up (> 20 years) showed that stems with a rougher surface (Ra: >0.4 μm) were more deleterious to the cement mantle and contributed to progressive stem loosening compared with stems with a polished surface [32]. In this study, the Elite Plus with a rougher surface posed a potential risk of more frequent radiolucent lines and AL.

Table 5 summarizes clinical results for the C-stem. Purbach et al. [33] reported survivorship rates of 100% at 10 years and 98.96% at 14 years for the C-stem, with AL or stem fracture as the endpoint. Junnila et al. [29] reported a 10-year survivorship rate of 95.8% in a registry study, whereas Walsh et al. [34] reported a 10-year survivorship rate of 95.0%. Focusing on the risk of PPF, Barheh et al. [35] reported 10- and 15-year survivorship rates of 99.0% and 97.8%, respectively. Our findings are comparable, with 10-year survival rates of 100% for loosening and 96.6% for any revision surgery.

The C-stem, classified as a "taper-slip" stem, permits controlled subsidence, creating compressive stresses at the bone-cement interface, which may reduce loosening. However, three PPF cases were noted in the C-stem group, showing a lower survival rate with PPF as the endpoint compared with the Elite Plus group.

While cementless stems have higher PPF rates, taper-slip stems also show increased PPF rates compared with composite-beam cemented stems [36–39]. The collarless polished tapered design may act as a wedge within the cement mantle, generating stress risers that can induce complex Vancouver B fractures following minor trauma [40]. Patients with taper-slip stems, particularly those with bone fragility, may therefore be at an increased risk for PPF.

Lamb et al. reported several risk factors for PPF following total hip replacement using polished taper-slip cemented stems from the National Joint Registry for England, Wales, Northern Ireland and the Isle of Man. Their results indicated that an increased risk of PPF revision was associated with polished taper-slip stems that were short, had high offset, were used with large femoral heads, were made of cobalt-chromium, or had round cross-sectional shapes [41]. The C-stem has a relatively short stem length and features round cross-sectional shapes distally; thus, the largest possible size of the

**Table 4** Summary of clinical outcomes of the elite plus stem as reported in other studies

| Author | Published year | Hips | Follow-up term (years) | AL | | PPF | | Revision (loosening) | | Revision (any reason) | | Rev. + loosening | | Surgical approach | Acetabular component | Bone cement |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | *N* | Survival rate | *N* | Survival rate | *N* | Survival rate | *n* | Survival rate | *n* | Survival rate | | | |
| Norton et al. [9] | 2002 | 29 | 3 | - | - | - | - | - | - | 9 | - | 15 | 32.4% (5 years) | AL | Hylamer | Palacos R (acetabular), Simplex (femur) |
| Brokelman et al. [10] | 2003 | 193 | 5.9 | - | - | 1 | - | - | - | 5 | 96.9% (6 years) | - | - | PL | (polyethylene) | - |
| Walton et al. [11] | 2005 | 234 | 6.4 | - | - | - | - | 9 | - | - | 96.25% (6 years) | 52 (30.9%) | - | - | Hylamer | Palacos R, Palacos LV |
| Rowsell et al. [12] | 2005 | 268 | 4.5 | 12 | - | 1 | - | 5 | 98.1% (6 years) | 12 | 95.5% (6 years) | 17 | 93.1% (6 years) | DLA, PL | Charnley Elite range, Trilogy | Palacos R, Palacos LV, Simplex, CMW 3 |
| Hauptfleisch et al. [13] | 2006 | 118 | 9 | 14 | - | 1 | - | 12 | - | - | 83% (10 years) | 24 | 59% (10 years) | DLA | LPW, Ogee | (low viscosity) |
| Kim et al. [14] | 2007 | 184 | 11.2 | 2 | - | 2 | - | 2 | - | 4 | 99.5% (12 years) | 3 | - | PL | Duraloc | Simplex P |
| Nixon et al. [15] | 2007 | 127 | 7.7 | 35 (28%) | - | - | - | - | - | - | - | - | - | - | - | - |
| Ollivere et al. [16] | 2009 | 234 | 12 | 26.8–28.8% (12 years) | - | - | - | 18 (11.8%, 12 years) | - | 19 | 93.9% (10 years) 88.0% (12 years) | 63.4% (12 years) | - | AL | (Hylamer) | (Palacos R, Palacos LV) |
| von Schewelov et al. [17] | 2010 | 114 | 6.5 | 15 | 98.0% (7 years) 92.0% (10 years) | - | - | 8 | - | 9 | - | - | - | DLA | Ogee Enduron, Hylamer | Palacos + gentamicin |
| Irie et al. [18] | 2012 | 97 | 8 | 5 | 96% (8 years) | - | - | 0 | 100% (8 years) | 7 | - | - | - | PL | Hylamer Ogee, Wrobeski Offset Bore, Charnley Ogee | - |
| Goto et al. [19] | 2018 | 173 | 11.6 | 1 | 100% (10 years) 98.1% (15 years) | 0 | - | 1 | 100% (10 years) 97.1% (15 years) | 7 | 95.0% (10 years) 88.4% (15 years) | - | - | DLA | LPW, FPW, Offset bore, Ogee | CMW1, Endurance |
| Our study | 2021 | 89 | 15.8 | 3 | 97.7% (10 years) | 0 | 100% | 2 | 97.7% (10 years) | 4 | 96.6% (10 years) | 4 | 96.6% (10 years) | AL, PL | Duraloc, Charnley, Elite Plus | Simplex, Endurance |

* Same study group

**Table 5** Summary of clinical outcomes of the C-stem as reported in other studies

| Author | Published year | Hips | Follow-up term (years) | AL | | PPF | | Revision (loosening) | | Revision (any reason) | | Rev. + loosening | | Surgical approach | Acetabular component | Bone cement | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | *n* | Survival rate | *n* | Survival rate | *N* | Survival rate | *n* | Survival rate | *n* | Survival rate | | | | | |
| Wrobeski et al. [20] | 2003 | 71 | 6 | - | - | 1 | - | 0 | - | 0 | - | 0 | - | - | Hylamer | CMW (acetabular), CMW1 (femur) | ** | |
| Purbach et al. [33] | 2013 | 621 | 13 | 0 | - | - | - | 0 | 100%* (10 years) 98.96%* (14 years) | 34 | - | - | - | - | UHMWPE, Hylamer | CMW2 (acetabular), CMW1 (femur) | ** | *including stem fracture |
| Junnila et al. [30] | 2016 | 2082 | 7.8 | - | - | - | - | - | - | - | 96.4–97.5% (7 years) 95.8% (10 years) | - | - | - | - | - | | Registry data |
| Walsh et al. [34] | 2022 | 321 | 5.6 | 0 | - | 1 (0.3%) | - | 0 | - | 7 | 95% (10 years) | - | - | DLA | Charnley Elite Plus, Marathon | Palacos R+G | | |
| Barheh et al. [34] | 2023 | 500 | 15 | 3 | - | 7 | 99.0% (10 years) 97.8% (15 years) | 1 | - | 14 | - | - | - | PL | - | Palacos R+G | | |
| Our study | 2021 | 42 | 11.7 | 0 | 100% | 3 | 92.9% (10 years) | 0 | 100% (10 years) | 2 | 95.2% (10 years) | 2 | 95.2% (10 years) | AL, DAA | Elite Plus, Ogee, Charnley, Trident | Simplex, Endurance | | |

** Same study group

C-stem was selected in this study. Some concerns about potentially thin and incomplete cement mantle around the stem might be raised. However, excellent results were obtained with the canal-filling technique using the Charnley-Kerboull and Ceraver-Osteal stems [42–44]. Additionally, Walsh et al. reported successful total hip replacement outcomes with the canal-filling technique using a triple-tapered stem [34].

Stem alignment was generally satisfactory in both groups, although the Elite Plus group displayed more frequent varus alignment compared to the C-stem group. Two of the three PPF cases occurred in patients with varus alignment, which has been associated with an increased risk of PPF. For example, Alpaugh et al. [45] found that valgus alignment significantly increased the risk of PPF (odds ratio = 2.69, $p = 0.079$). This suggests that malalignment may contribute to PPF in our cohort.

This study has some limitations. Notably, it was not a randomized controlled trial, and baseline differences among patient groups, including primary hip disorders, surgical approach, acetabular cup type, and femoral head diameter, may have influenced outcomes. In particular, differences in femoral head diameter and surgical approach could have contributed to the dislocation rates observed in the Elite Plus group. Additionally, more patients with rheumatoid arthritis and femoral fragility were in the C-stem group, potentially affecting PPF prevalence.

## Conclusions

This study compared the Elite Plus with the C-stem in terms of their clinical and radiographic outcomes. Both the Elite Plus and C-stem demonstrated acceptable 10-year clinical outcomes; however, the Elite Plus exhibited more frequent loosening and radiolucent lines than the C-stem. While Elite stems are no longer available in several countries, assessing patients with these stems is important to detect loosening.

The C-stem achieved stable cement-bone interfaces, although PPF occurred in several cases. Given that the C-stem remains popular in numerous countries, identifying the risk of PPF is crucial. Implantation of large-sized stems may prevent PPF. Differences in stem fixation philosophy and surface finish could contribute to some differences in clinical and radiographic outcomes between the groups.

**Abbreviations**

USA United States of America
PPF Periprosthetic fracture
AL Aseptic loosening
JOA Japanese Orthopedic Association
THA Total hip arthroplasty

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SN, SM, TN, CS, TK, YS, and SI were involved in the study design. SN, SM, TN, CS, and SI interpreted the data. SN, SM, CS, and SI were involved in data analysis. All authors critically revised the manuscript, approved the manuscript to be published, and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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**Data availability**

The data used to support the findings of this study are available from the corresponding author upon request.

## Declarations

**Ethical approval and consent to participate**

Informed consent to participate was provided through an opt-out method. The research protocol was approved by the Institutional Review Board of Matsudo City General Hospital (No. R5-3) in compliance with the principles of the Declaration of Helsinki and its contemporary amendments.

**Consent for publication**

Not applicable.

**Competing interests**

The authors declare no competing interests.

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## Publisher's note