

LINE-TO-LINE CEMENTATION IN HIP ARTHROPLASTY: WHAT IS THE CURRENT ROLE OF THE "FRENCH PARADOX"?

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SUMMARY

Background: Stable fixation in cemented total hip arthroplasty (THA) traditionally requires a uniform cement mantle of 2 mm to 4 mm to prevent aseptic loosening. However, the "French Paradox" challenges this convention by utilizing a line-to-line cementing technique with canal-filling stems, resulting in a thin or incomplete cement interface.

Objective: This review evaluates the clinical outcomes, biomechanical properties, and current evidence surrounding the line-to-line cementation philosophy in THA.

Key Points: Biomechanical studies, including finite element analysis and cadaveric models, indicate that canal-filling stems provide superior rotational stability and effective hoop stress distribution despite a reduced cement mantle. Line-to-line techniques demonstrate higher cement pressurization and improved interdigitation compared to oversized broaching. Clinical data for stems such as the Charnley-Kerboull and C-Stem show long-term survivorship rates exceeding 95% at 10 to 17 years, with low rates of radiological loosening. Radiostereometric analysis confirms significantly lower retroversion in line-to-line groups compared to standard techniques, with no significant difference in subsidence. While effective for both standard and short polished stems, the literature lacks a standardized definition of the "French Paradox," with descriptions ranging from thin homogeneous mantles to discontinuous cementation patterns.

Conclusion: The line-to-line cementation technique provides reliable long-term fixation and clinical success in THA. Despite contradicting traditional mantle thickness recommendations, the approach is biomechanically sound for various stem designs and bone qualities, though further prospective studies utilizing patient-reported outcome measures are required to standardize clinical protocols.

KEYWORDS

Arthroplasty, Replacement, Hip; Bone Cements; Hip Prosthesis; Prosthesis Failure; Biomechanical Phenomena

INTRODUCTION

The primary goal of cemented femoral stem fixation is to ensure stable fixation between the implant–cement–bone interfaces. Over time, implant fixation principles have evolved, leading to a classification of cemented stems into two main categories: taper slip (force-closed) stems and composite beam (shape-closed) stems [1]. Additional factors influencing fixation outcomes include broaching techniques, cementing techniques, and the thickness of the cement mantle.

To reduce aseptic loosening and stem revision, the minimal thickness of modern complete cement mantles is generally recommended to be 2 mm to 4 mm [6],[7]. Nonetheless, this knowledge has been challenged by paradoxical results obtained with two French-designed cemented stems, Charnley-Kerboul (Orthinox, Stryker Howmedica, France; current production: Groupe Lépine, Genay, France) and Ceraver Osteal (Ceraver, France), which utilize a cemented line-to-line press-fit technique [8].

This review aims to summarize the current evidence regarding the clinical outcomes, biomechanical validation, and ongoing controversies surrounding the French Paradox cementing technique in THA.

DIFFERENCES IN CEMENTATION

Cemented femoral stems can be classified based on their fixation mechanism into shape-closed and force-closed designs. Shape-closed stems are designed to be fully contained within the cement mantle, presenting a rough surface texture, collars, and curved geometries to ensure rigid fixation. Conversely, force-closed stems feature polished surfaces, tapered or wedged shapes, and are intended to subside gradually within the cement mantle postoperatively. Their stability derives from controlled subsidence under load, similar to a press-fit mechanism [9].

Standard cementation techniques, typically involving oversized broaching, have demonstrated long-term survival for both stem types. However, this approach may not be optimal for force-closed designs, which benefit from subsidence and micromotion to promote load distribution [9].

Composite beam (shape-closed) stems function as a rigid unit with the cement, minimizing relative movement and distributing forces evenly to the bone. Their design often includes collars and angular cross-sections to enhance load transfer, exemplified by Charnley-Kerboul and Ceraver Osteal stems. In contrast, taper-slip (force-closed) stems have gained popularity for their ability to accommodate physiological loading [10].

A specific cementation philosophy, the ‘French Paradox’, challenges conventional principles. This technique involves removing cancellous bone to fit a large, canal-filling stem, resulting in a thin or incomplete cement mantle. Despite contradicting traditional recommendations of mantle thickness, it has shown satisfactory outcomes with certain shape-closed stems, relying on stem geometry for stability [10].

FROM FINITE ELEMENT ANALYSIS TO EXPERIMENTAL VALIDATION —

The fixation of femoral stems using cement has been extensively studied through a combination of computational models, cadaveric experiments, and biomechanical tests to evaluate the influence of cementation techniques on implant stability. A finite element analysis (FEA) model of a Charnley-Kerboull stem in a cadaver femur was developed to simulate various clinical scenarios. Four stem sizes were analyzed (maximal canal-filling, canal-filling, undersized, and severely undersized), considering different types of bone support (trabecular-only, mixed, and cortical-only). The results showed that undersized stems consistently led to full-thickness cement mantle cracks, while maximal canal-filling stems provided superior rotational stability, regardless of bone support type [11] (Figure 1).

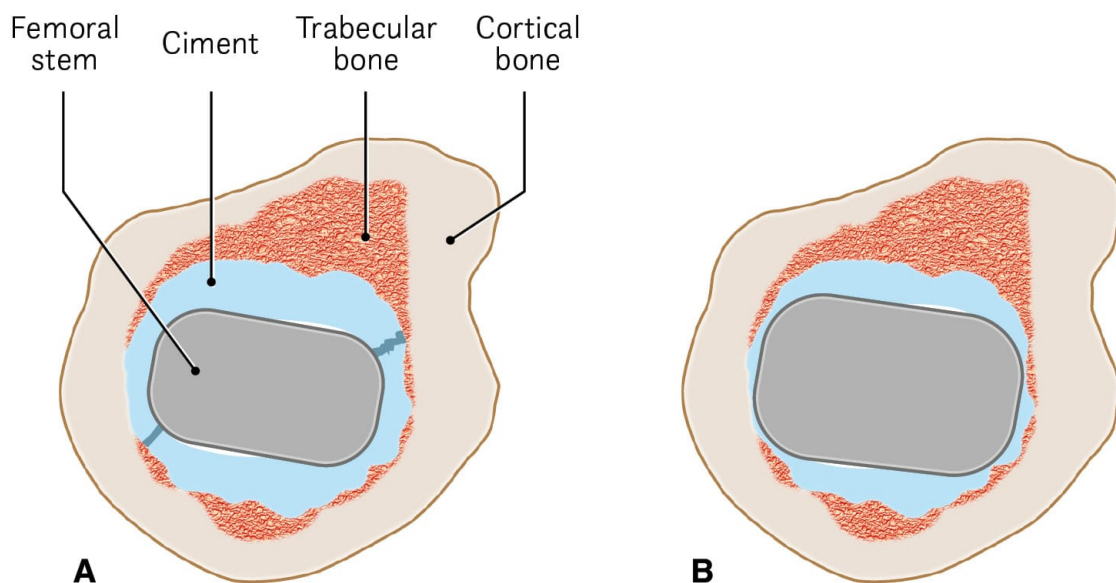


Figure 1: A. Crack development observed in the model with a severely undersized stem. B. Comparison with the model using a maximally canal-filling stem.

Complementary cadaver studies compared line-to-line cementing techniques, where the stem matches the broach size, to the standard oversized broach approach. Findings indicated that line-to-line cementing generated higher and more sustained pressurization, improving cement interdigitation but leading to a thinner mantle in certain areas [12].

Biomechanical tests with Charnley-Marcel-Kerboull stems demonstrated that thin cement mantles can still achieve effective hoop stress distribution without excessive subsidence, suggesting that highly polished stems may benefit from force-closed fixation behavior even with minimal cement thickness [13].

Additional in vitro studies explored the primary stability of cemented short stems, comparing undersized and line-to-line cementation strategies. Both techniques yielded similar results in terms of micromotion, migration, and fracture load, indicating comparable primary stability in osteoporotic bone [14]. However, for short polished stems, standard cementation appeared to minimize micromotion and cement cracking, suggesting it might be preferable in these cases [15].

Finally, a finite element analysis of prototype short stems implanted using both cementation strategies reinforced these findings, showing no significant differences in stiffness and strength (Figure 2). This supports the use of cemented short stems as a viable option for patients with poor bone stock, with line-to-line and undersized techniques providing similar biomechanical outcomes [16].

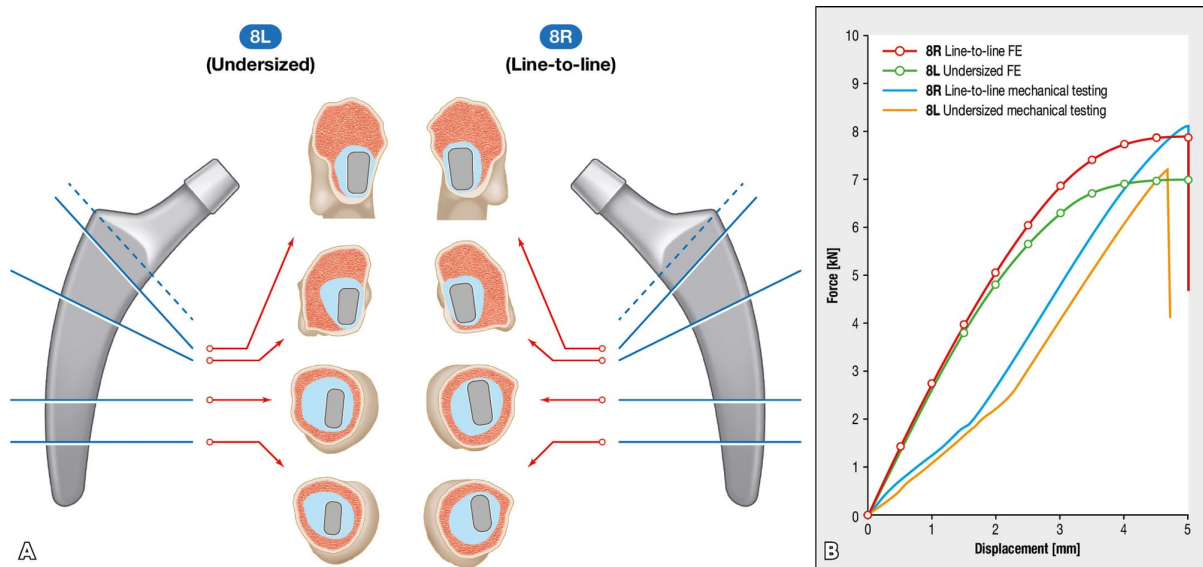


Figure 2: A. Canal filling comparison at different cross-sectional levels between undersized and line-to-line cementation technique. B. Force–displacement curves comparing the two cementation techniques with this short stem, as determined from mechanical tests and finite element analysis.

CLINICAL OUTCOMES

The ‘French Paradox’ cementing technique, characterized by line-to-line implantation of canal-filling stems, has been extensively investigated for its clinical and radiological outcomes. Historically, the Charnley-Kerboul stem, a polished double-tapered monobloc design, has demonstrated excellent long-term results using this philosophy.

In a study of 164 primary THA in 155 patients, the mean Merle d’Aubigné score improved significantly from 10.7 to 17.6 points ($p < 0.001$). At final follow-up, 74% of cases were rated as excellent, 22.1% very good, and only 2.6% good, with a minimal rate of poor outcomes [7].

In terms of survivorship, cumulative survival at 17 years was reported at 90.5% when revision of either component for any reason was considered, and an impressive 96.8% when focusing on radiological loosening of the femoral component. Age stratification highlighted better survival in patients older than 60 years (97.8%) compared to younger individuals (82.2%; $p = 0.016$) [7]. A randomized controlled trial comparing the ‘French Paradox’ cementing with standard techniques assessed femoral stem migration in 48 arthroplasties using radiostereometric analysis. Results indicated significantly lower retroversion in the line-to-line group at all timepoints up to 24 months ($p < 0.001$), with no significant difference in subsidence between the two methods ($p = 0.921$) [9].

The C-Stem (DePuy Synthes, Leeds, United Kingdom), another design utilizing the ‘French Paradox’ philosophy, confirmed these findings in a larger series of 321 cemented THAs. The 10-year implant survival was reported at

95%, with a low revision rate of 2% for all causes and no cases of aseptic loosening of the femoral stem [10]. However, this survival rate was slightly lower than literature benchmarks.

Regarding complications, a long-term series of 164 Charnley-Kerboul stems reported a median survival of 17.4 years, with only 2.4% post-operative complications, including dislocations and nonunion of the greater trochanter. Heterotopic ossification was observed in 9.8% of hips [7]. Revision surgeries were rare, with only seven stems revised, three for loosening and four for acetabular reconstruction purposes [7].

The role of stem length was addressed by comparing shortened AmisK (Medacta International, Castel San Pietro, Switzerland) stems to standard-length Charnley-Kerboul (Groupe Lépine, Genay, France) stems. At a 2-year follow-up, no significant difference in subsidence was found ($p = 0.73$), and cortical thickening was significantly lower in the shortened stem group (12% vs. 40%, $p = 0.003$) [17].

A decade-long follow-up of the Trilliance (Zimmer Biomet, Warsaw, United States) collarless triple-tapered polished stem implanted line-to-line via a direct anterior approach also demonstrated excellent results. The cumulative survivorship was reported at 100%, 97.6%, and 96.5% for various endpoints, confirming the robustness of the line-to-line technique even with newer stem designs [18].

OPEN ISSUES AND FUTURE PERSPECTIVES

The concept of the ‘French Paradox’ is not always clearly defined in the literature. Its origin appears to stem from the initial use of partial cementation with French-designed stems, such as the Charnley-Kerboul and Ceraver Osteal stems.

Today, the ‘French Paradox’ concept is more appropriately associated with the line-to-line cementing technique, where the stem and rasp are of identical size, resulting in minimal space for the cement mantle. This approach contrasts with the more commonly used undersized cementing strategy, where the stem is intentionally one size smaller than the rasp. This undersizing technique was originally applied to composite beam-type stems.

Studies reporting clinical outcomes, including PROMs (Patient-Reported Outcome Measures) or other functional scores, are scarce in the literature, both for short- and long-term follow-ups.

Regarding implant survivorship, many studies on the ‘French Paradox’ cementing technique lack control groups. Nevertheless, this technique has demonstrated good survivorship outcomes across various stem designs.

From the available evidence, no specific causes of failure have been identified that would differentiate this technique unfavorably from other stem designs or cementing methods.

Biomechanical investigations, including cadaveric and finite element analyses, suggest that the line-to-line cementing technique is applicable even with short stems and in the setting of osteoporotic bone.

It is important to note that the literature does not consistently define the ‘French Paradox’. While it universally refers to partial cementation, some sources describe it as a line-to-line technique resulting in a homogeneous cement mantle (<2 mm thickness), whereas others refer to it as producing a discontinuous (possibly patchy or irregular) cementation pattern.

CONCLUSIONS

The ‘French Paradox’ cementation technique, characterized by line-to-line stem insertion with a thin cement mantle, challenges traditional principles of cemented femoral stem fixation. Despite the contradiction with established recommendations advocating for a 2–4 mm cement mantle, clinical evidence demonstrates that this philosophy achieves excellent long-term survivorship, with low rates of aseptic loosening and favorable functional outcomes across different stem designs.

Biomechanical studies support the use of line-to-line cementation in both standard-length and short stems, even in osteoporotic bone conditions, suggesting that implant design, surface finish, and force-closed fixation mechanics may mitigate concerns regarding mantle thickness. However, the lack of prospective comparative studies, especially those incorporating PROMs, represents a significant gap in the literature.

Furthermore, the heterogeneous use of the term ‘French Paradox’ across publications underscores the need for a clear, standardized definition. Future research should aim to validate clinical outcomes, refine biomechanical understanding, and define best practices for this cementation philosophy.

While further investigation is warranted, current evidence indicates that, when properly applied, the ‘French Paradox’ cementation technique represents a viable and reliable option in total hip arthroplasty, combining historical success with modern surgical strategies.

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