The Knee 62 (2026) 104561

Contents lists available at ScienceDirect

The Knee

journal homepage: www.elsevier.com/locate/thekne

# Initial stability of surface vs. full cemented tibial components under cyclic loading

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ARTICLE INFO

*Article history:*
Received 30 December 2025
Revised 21 May 2026
Accepted 29 June 2026

*Keywords:*
TKA
Cementing techniques
Aseptic loosening
Full cementation
Surface cementation
Initial stability

ABSTRACT

*Background:* Total Knee Arthroplasty is a common treatment for end-stage osteoarthritis with excellent long-term survival. However, aseptic loosening of the tibial component remains a concern and may be influenced by cementing technique. Radiostereometric analysis studies indicate that early tibial migration increases the risk for later loosening. There is no consensus regarding how the tibial component should be cemented.
*Objectives:* To compare surface cementation (SC) and full cementation (FC) of the tibial component with respect to migration, micromotion, and bonding strength and to assess correlation between cement thickness and implant movement.
*Methods:* Using a composite tibia model, we compared SC ($n$ = 5) with FC ($n$ = 5) of the NexGen Stemmed Option tibial baseplate. Groups underwent 20,000 loading cycles at a maximal axial load of 1780 N at a 1 Hz rate. Migration and micromotion were measured with Linear Variable Differential Transformers. Bonding strength was assessed in a push-out test.
Parametric statistics were used for group comparisons.
*Results:* Mean anterior migration was 0.7 µm (SD ± 0.8) for FC and –1.3 µm (±1.5) for SC ($p$ = 0.03). Mean anterior micromotion was 1.1 µm (± 0.8) for FC and 12.3 µm (±7.2) for SC ($p$ = 0.03). Posterior implant movement were similar between groups. The FC-group demonstrated higher mean bonding strength (7655 N ± 1613) compared with SC (4541 N ± 1202) ($p$ = 0.009). Greater anterior cement thickness correlated with reduced micromotion ($r$ = –0.7, $p$ = 0.02).
*Conclusion:* Full cementation resulted in greater anterior stability and bonding strength compared with surface cementation. These findings suggest that full cementation reduces initial movement for NexGen Stemmed Option tibial baseplates.
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## 1. Introduction

Total knee arthroplasty (TKA) remains the gold standard for treating end-stage osteoarthritis with excellent implant survival at 95% 10 years after surgery [1].Though being a successful treatment for degenerative joint disease, aseptic tibial

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https://doi.org/10.1016/j.knee.2026.104561
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loosening as a revision cause has not decreased over 2 decades [2]. Aseptic loosening due to increased osteoclastic activity because of polyethylene wear is a well-known mechanism of aseptic loosening. The mechanism has been studied and approached with innovations such as highly cross-linked polyethylene, improved polyethylene sterilization, and better locking mechanisms of polyethylene inserts, which has contributed to a decreased occurrence of osteoclast-driven loosening [3]. Now, aseptic loosening seems to be driven by a mechanism of debonding between implant and cement [4,5]. The cause of debonding is still debated, and various theories have been proposed as described by Sundfeldt and colleagues [6]. Multiple randomized radiostereometric analysis (RSA) studies indicate that migration, the maximal total point motion of the tibial component over time, is associated with early aseptic tibial loosening [7,8]. The cementing technique of the tibial component, whether to cement both baseplate and stem or baseplate only, is a debatable aspect of TKA surgery [9,10]. DePuy Synthes and Zimmer Biomet specifically recommend to cement both baseplate and stem for their implants when the cement is in a sticky phase [11,12].

Advocates of full cementation argue that this increases the implant–cement contact area, creating a continuous cement mantle that improves initial fixation, limits micromotion, and enhances resistance to implant debonding [13,14]—mechanisms that are thought to be critical given the established association between early tibial migration and later aseptic loosening [7,8]. A Delphi consensus study surveying 80 expert orthopaedic surgeons in the UK recommended cementing both baseplate and stem [15]. In contrast, proponents of surface cementation emphasize potential advantages related to more physiological load transfer. By leaving the stem uncemented, stresses may be distributed more proximally beneath the baseplate rather than transferred distally along the stem, which could theoretically reduce stress shielding of cancellous bone beneath the tibial tray [16]. Surface cementation may also facilitate future revision surgery by preserving bone stock and simplifying implant and cement removal in revision surgery.

There is, however, no international consensus regarding the optimal extent of cement application for stemmed tibial components in primary TKA [17,18]. Additionally, registry data do not currently capture cementing technique in sufficient detail, and in vivo studies are limited by confounding surgical and patient-related factors. Consequently, controlled biomechanical investigations focusing on early implant stability are needed to isolate the mechanical effect of cement placement.

Other aspects that may influence initial stability is implant design [19,20], especially roughness and cement pockets, and bone marrow contamination [4,20–22].

Our primary objectives were to compare initial stability (migration and micromotion) and bonding strength between two cementing techniques (full cementation vs surface cementation) under standardized loading conditions. Secondary objectives were to investigate the correlation between cement mantle thickness and micromotion as well as migration.

## 2. Methods

To investigate the effect of cementation technique on initial stability and bonding strength, we used an experimental design inspired by previous studies [20,21]. We used an in vitro composite tibia model (Tibia Plateau Block, Cellular Core 12.5 PCF with Solid Foam Shell 40 PCF from Sawbones™) (Figure 1). This model mimics the tibial macro and micro anatomy apart from having closed pores as opposed to open porous structure found in cancellous bone. The size of each pore ranges from 0.5–1 mm [23,24]. A widely used tibial baseplate in Norway prior to being drawn from market [25], the NexGen Stemmed Option (Zimmer Biomet® Warsaw, Indiana, USA) size 4, was implanted into the bone model (Figure 1). A 14 mm ultra-high-molecular-weight polyethylene cruciate retaining (CR) insert designed for the specific tibial implant was inserted onto the implant. This insert was selected to provide sufficient structural stiffness during the experimental gait simulation. Thicker inserts are commonly used in vitro testing to avoid excessive polyethylene deformation or insert–tray toggling that may occur with thinner inserts under repeated loading, which could confound measurements of tibial baseplate micromotion and migration [21,26]. Palacos R + G polymethyl methacrylate (PMMA) high viscosity bone cement (Heraeus Medical LLC, Werheim, Germany) was used to fixate the implants to the plastic bone models.

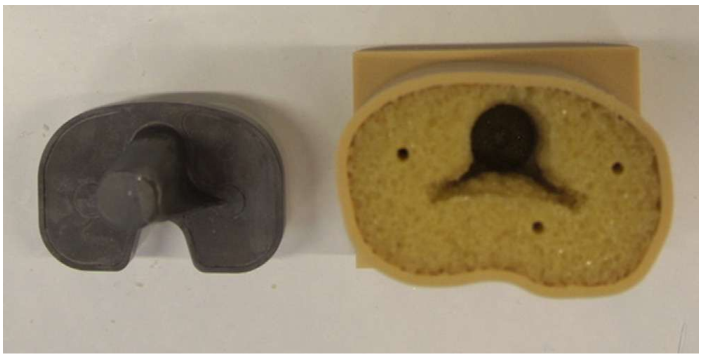

**Figure 1.** NexGen Stemmed Option size 4 tibial plateau (left). Tibia Plateau Block, Cellular Core 12.5 PCF with Solid Foam Shell 40 PCF after preparation (right).

We measure our outcomes as follows:

1) Implant stability is measured as both migration and micromotion. Migration and micromotion are both measurements of movement but are inherently different; migration is the change in position of the baseplate over time. It can be considered as cumulative micromotion over time as used clinically in RSA studies. Micromotion is the movement of the baseplate during one loading cycle. Both outcomes were measured in micrometres (μm).
2) Bonding strength is measured as the force needed to separate the implant from the bone model. Outcome was measured in Newton (N).

Secondary outcomes were

3) Correlation between cement mantle thickness and micromotion as well as migration using Pearson's correlation.

### *2.1. Bone preparation*

The bone models were prepared with surgical instruments, designed for the NexGen Stemmed Option size 4 tibial plates. A metal guide was mounted using corresponding nails and hammer. Consecutively a 16.7 mm drill and drill-guide were used to create the cavity for the stem. Finally, a reamer was used to create space for the stem wings. An experienced TKA surgeon (ONF), supervised the bone preparation, to ensure the most operation theatre-like procedure as possible. The bone model and implant were weighed separately before cementation to both determine their respective masses and gauge the amount of cement used for each of the groups.

### *2.2. Cementation*

The Palacos R + G bone cement was stored at 3°C and taken out of the fridge immediately before cement mixing, to mitigate the effect of eventual variations in room temperature. The components were mixed under vacuum in a Palamix system to avoid accumulations of air in the cement as well as providing a cement reservoir for cement gun application.

First, the liquid- and powder components of the bone cement were poured into the Palamix container and were mixed manually under vacuum for 30 s [27]. At the 2-minute mark, cement was applied with the cement gun, first to the implant in a sticky phase and subsequently to the cut surface of the bone model in a doughy phase [12]. For the Full Cemented (FC) group ($N = 5$), cement was applied to the plateau and stem of the implant, into the stem-canal and to the cut surface of the bone. For the Surface Cemented (SC) group ($N = 5$), cement was only applied to the plateau of the implant and to the cut surface of the bone (Figure 2).

After cement application, the implant was inserted into the bone model and fixated using manual compression, impaction tool, and hammer. Following fixation, 4 min after cement mixing, the specimens was installed into an Instron machine where an axial force of 50 N was applied until 13 min from mixing start. The application of axial pressure simulates "extension under compression" which is done in the operating theatre. Any cement that overflowed from the bone-implant interphase was removed. Lastly, the specimens would be placed in a heating cabinet with an internal temperature of 37°C for 30 min to ensure standardized, physiological-like curing for the specimens. After extracting the specimens from the cabinet, cement mantle thickness, defined as the distance between the lower bound of the tibial baseplate and the upper bound of the bone model, was measured with a caliper anteriorly, posterior-medially, and posterior-laterally. The complete penetration including cement mantle thickness as well as penetration into the bone was not measured due to the composite bone properties (see section 2.0).

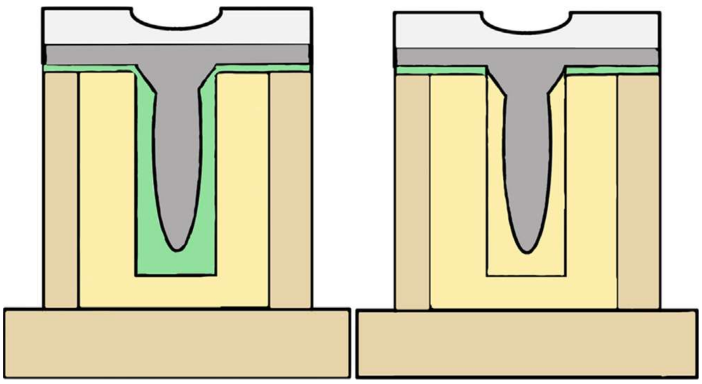

**Figure 2.** Illustration of cement placement for Full Cemented group (left) and Surface Cemented group (right).

### 2.3. Gait simulation

Twenty-four hours after preparation, the specimens were installed into an MTS Model 858 Mini Bionix II® test-rig to be subjected to cyclic loading. The load simulated the gait of a 75 kg person, and the specimens were subjected to 20 000 gait cycles with a load ranging from 100 N-1.76 kN and frequency of 1 Hz (Figure 3). This equivalates approximately 2–3 weeks of walking postoperatively. To measure tibial baseplate movement in relation to the bone model and axial displacement, we used three Linear Variable Differential Transformers (LVDTs, manufactured by Solartron Metrology®, Leicestershire – United Kingdom; model: AX/1.5/S, range), with a range from ±1.5 mm and resolution of <0.1 μm. Movement downwards (subsidence) was registered as negative, and movement upwards (lift-off) was registered as positive. The LVDTs were mounted to the specimens using customized holders and metal plateaus to provide support to the LVDTs during the cyclical loading program. We used the same placement of LVDTs for all specimens; direct anterior, posteromedial and posterolateral. The metal plateaus were placed 8 mm beneath the lower bound of the baseplate in the respective placements as the holders. To further mimic in vivo gait conditions, a metal plate was designed to resemble femoral condyles, ensuring the dispersion of forces across the specimens to resemble human joint articulation. The setup for gait simulation is depicted in Figure 4. Data from the LVDTs were collected using a Digital to Analog Converter (DAC) unit, the Fylde microANALOG 2, from Fylde Electronic Laboratories (Preston, England). Further processing of the raw data was done in Matlab, generating motion curves, implant migration and implant micromotion for each of the LVDTs.

### 2.4. Bonding strength

Subsequent to the gait simulation, we investigated bonding strength between the implant and bone cement through a pushout test. The specimens were prepared for the pushout by drilling a hole (10 mm wide) through the bottom of the bone model exposing the implant's stem. Afterwards, the specimens were embedded in a metal cylindrical container with Meliodent only exposing the implant-bone interphase, to strengthen the construction. A load was then applied through a metal pushout rod that was pressed directly to the stem at a displacement rate of 0.05 mm/s and the load recorded until the baseplate loosened from the cement-bone interphase or cement-implant interphase (Figure 5).

## 3. Statistics

Data from posteromedial and posterolateral LVDTs were averaged, representing posterior measurements of migration, micromotion and cement thickness. Parametric statistical methods were used as the data fulfilled the assumption of normal distribution through q-q plot inspection and Shapiro- Wilk test. In addition, variance analysis showed similar variance between groups apart from anterior micromotion. When comparing differences between the SC-group and the FC-group, we used unpaired Student's *t*-test. Welch's *t*-test was applied when comparing anterior micromotion. To compare differences between anterior and posterior positions, paired Student's *t*-test was used. Pearson's correlation was used to investigate the relationship between cement thicknesses and implant movement. P-values <0.05 were considered statistically significant.

A post–hoc assessment of statistical power based on our bonding strength data, indicated adequate statistical power (>80%) even with $n$ = 5 per group. Outcomes with smaller effect sizes may have been underpowered.

Analyses were conducted in Stata SE 18. Figures were designed using R statistical package (R Foundation for Statistical Computing) 4.2.3.

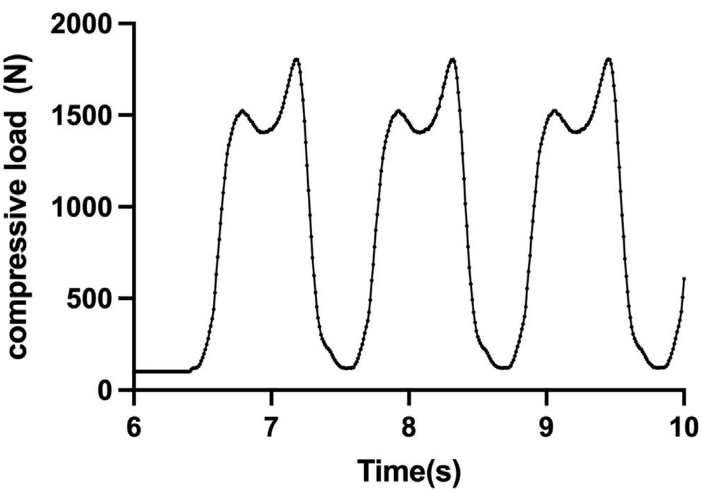


**Figure 3.** Graph illustrating the cyclic compressive load delivered to the specimens during gait simulation.

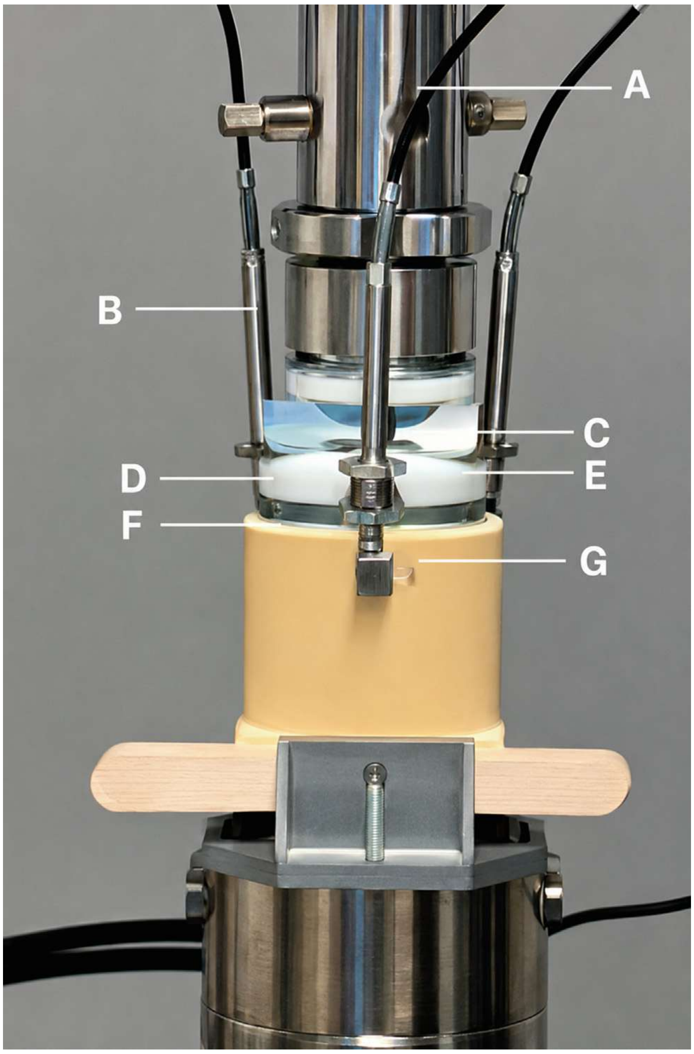


**Figure 4.** Test setup for cyclic loading. A) Hydraulic mechanical testing machine, B) Linear variable differential transformers (LVDT) placed anteriorly, posterolaterally and posteromedially C) femoral condyles D) polyethylene insert E) LVDT holder F) cement mantle G) Sawbone model.

## 4. Results

### *4.1. Implant stability*

Migration: After cyclic loading, the FC-group had an average anterior migration (lift-off) of 0.7 µm (SD ± 0.8) and SC-group had migration (subsidence) of −1.3 µm (±1.5), $p = 0.03$. No difference in posterior migration was found between the FC-group and SC-group (Table 1, Figure 6A)). For paired analysis, FC-group showed less anterior migration compared to posterior. No difference in migration between anterior and posterior position was found for SC group (Figure 6A)) Absolute migration regardless of direction revealed no difference between groups (Table 1).

Micromotion: There was less micromotion anteriorly for FC-implants, 1.1 µm (±0.8) vs SC-implants 12.3 µm (±7.2), $p = 0.03$. No difference in posterior micromotion was found (Table 1, Figure 6B)). For paired analysis, FC-group showed less anterior micromotion compared to posterior. No difference in micromotion between anterior and posterior position was found for SC-group (Figure 6B)).

### *4.2. Bonding strength*

When comparing the bonding strength, we found a higher average bonding strength for the FC group, 7655 N (±1613) compared to 4541 N (±1202) in the SC group, $p = 0.009$ (Table 1, Figure 6C)).

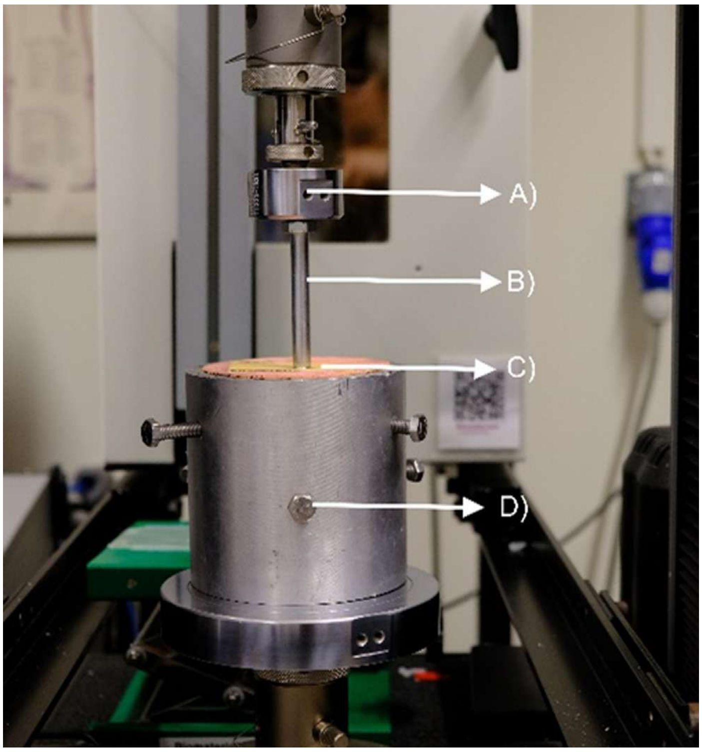


**Figure 5.** Bonding strength test setup. A) Instron mechanical testing machine B) Pushout rod C) Sawbone D) Cylindrical metal container with bone model with tibia baseplate embedded inside (not visible).

**Table 1**
Results from gait-simulation, bonding strength and cement thickness. All values are mean (±standard deviation, SD).

| Outcome | FC | SC | P-value |
|---|---|---|---|
| Anterior migration µm, Mean (SD) | 0.7 (±0.8) | −1.3 (±1.5) | 0.03 |
| Posterior migration µm, Mean (SD) | −3.2(±2.1) | −3.0 (±3.3) | 0.90 |
| Absolute anterior migration µm, Mean (SD) | 0.90 (±0.59) | 1.35(±1.35) | 0.74 |
| Absolute posterior migration µm, Mean (SD) | 3.2(±2.1) | 3.0(±3.3) | 0.47 |
| Anterior micromotion µm, Mean (SD) | 1.1 (±0.8) | 12.3 (±7.2) | 0.03* |
| Posterior micromotion µm, Mean (SD) | 20.4(±2.9) | 17.5(±6.9) | 0.4 |
| Bonding strength N, Mean (SD) | 7655 (±1613) | 4541(±1202) | 0.009 |
| Anterior cement thickness mm, Mean (SD) | 2.6(±0.3) | 0.4(±0.2) | 0.0001 |
| Posterior cement thickness mm, Mean (SD) | 1.1 (±0.1) | 0.5(±0.2) | 0.01 |

* Estimated with Welch *t*-test.

### 4.3. Cement thickness

Anteriorly the FC group had a mean thickness of 2.6 mm (±0.3), SC 0.4 mm (±0.2), $p = 0.0001$. Posteriorly the thickness was 1.1 mm (±0.1) for the FC-group, and 0.5 mm (±0.2) for the SC-group, $p = 0.01$ (Figure 6D)). We also observed during preparation that for the FC-group, overshooting cement would flow out the front. This tilted the baseplate in a posterior angle (Figure 7). Further, anterior cement thickness was greater than posterior cement thickness in the FC group, $p = 0.0003$. A thicker cement mantle led to less micromotion ($r = -0.7$, $p = 0.02$). (Figure 8). No significant correlation was found for posterior cement mantle thickness and posterior migration nor micromotion.

## 5. Discussion

This study compared full cementing and surface cementing of the NexGen Stemmed Option tibia baseplate using an in vitro model reflecting results in a short-term perspective. It demonstrated significantly less anterior movement measured by micromotion and migration when both the baseplate and stem were fully cemented. Fully cementing (FC) the implants also led to higher bonding strength. A thicker cement mantle decreased micromotion and was obtained with a full cementing technique.

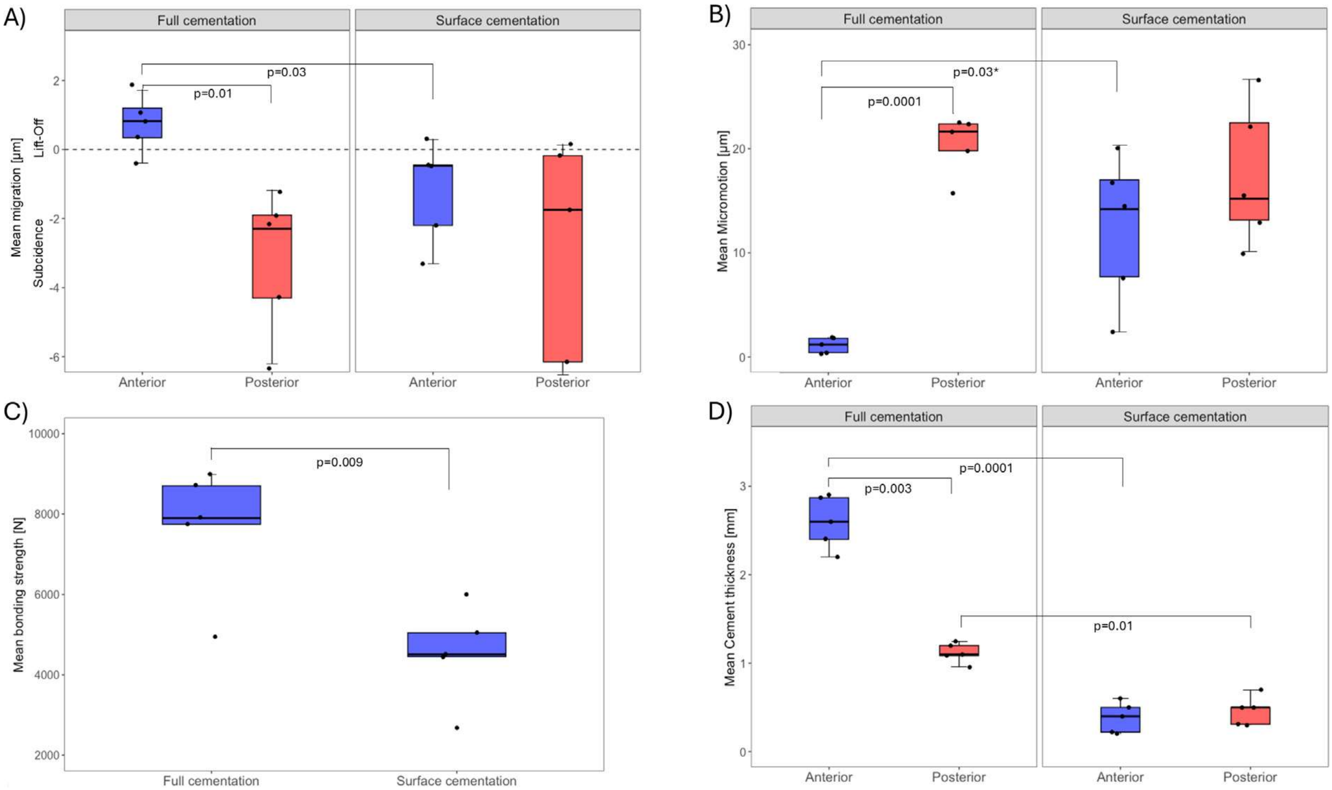


**Figure 6.** Bar – and dot plots comparing FC group and SC group. A) Mean anterior and posterior migration B) Mean anterior and posterior micromotion. *Welch's test. C) Mean bonding strength D) Mean anterior and posterior cement thickness.

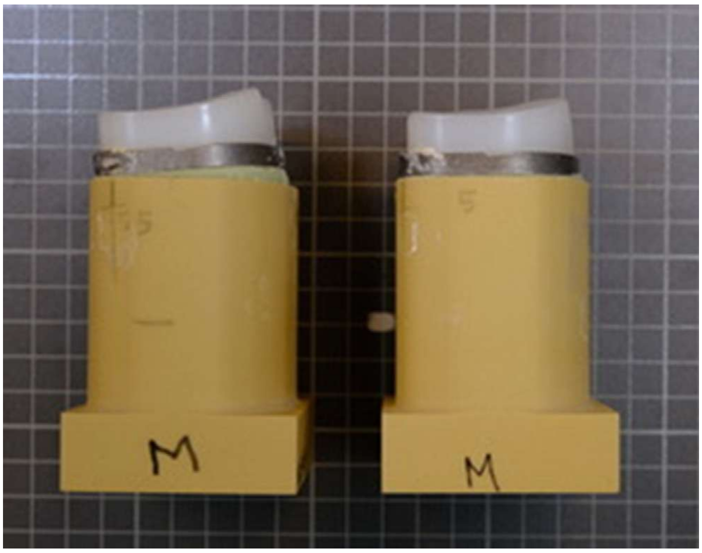


**Figure 7.** Photography of FC (left) and SC (right). Note difference in cement mantle thickness anterior to posterior and baseplate posterior tilt on FC.

## *5.1. Stability*

We found that the FC cemented implants exhibited greater stability demonstrated by reduced micromotion and migration. Although micromotion values were small in absolute terms, differences in the low–micrometre range are biomechanically relevant in experimental studies; lower micromotion is considered indicative of a more stable fixation. Meta-analyses of cemented implants propose a threshold of migration below 300 µm at 6 months to be safe and levels exceeding 1100 µm to be unacceptable [8,28].

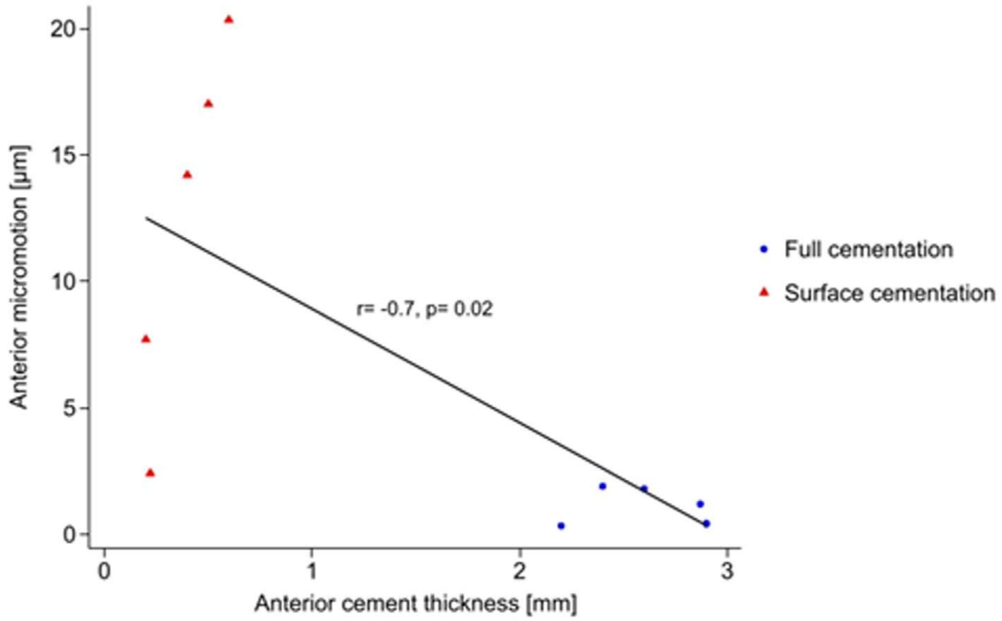


**Figure 8.** Regression model illustrating correlation between anterior cement thickness and anterior micromotion. Thinner cement resulted in more micromotion.

The FC-group tended to lift off more in our experimental setup, likely due to a posterior offset of the cyclic load. On the contrary, the SC- group tended to subside and migrated more. Excess cement extrusion anteriorly for the FC group resulted in posterior inclination of the baseplate, which in turn caused a posterior shift of the femoral condyle contact point during gait simulation. The altered joint geometry likely biased the applied load posteriorly and provides a plausible mechanical explanation for the anterior lift off pattern observed in the FC group. The fact that excess cement flow was not observed in the SC group likely reflects the absence of posterior tilt and a more compliant construct that accommodated posterior loading through subsidence rather than rotation.

Previous in vitro studies report diverging findings; Some studies have shown no difference in migration between FC and SC implants [29], while others have demonstrated reduced micromotion with full cementation [30]. Similarly, comparisons have shown less micromotion in FC implants compared to cementless implants [31].

The findings of the present study should be interpreted in the context of a heterogeneous body of experimental and clinical literature, in which several radiostereometric, biomechanical, and clinical outcome studies have reported no significant difference in early migration, fixation performance, or survivorship between FC and SC of the tibial component, although 3 studies have shown better results for FC(10). These studies suggest that cementing the tibial stem is not universally required to achieve adequate initial fixation and that satisfactory stability can be obtained with surface cementation alone, particularly in implant designs with favourable geometry and surface roughness or sufficient cement penetration beneath the baseplate. Currently no studies conclude SC to provide increased stability compared to FC. Differences in implant design, cement handling, loading protocols, measurement techniques, and follow–up duration likely contribute to these variable findings.

Advocates of full cementation argue that cementing both baseplate and stem minimizes micromotion, creating a more stable construct as shown in our study. In a randomized RSA study, Hyldahl and colleagues found less migration for metal-backed AGC implants (Biomet, South Wales, United Kingdom) when both stem and baseplate were cemented, though this was not observed for all polyethylene tibia AGC components [14,32] On the contrary, Saari and colleagues found no difference between techniques in a similar study, assessing the metal-backed Profix design (Smith and Nephew, Memphis, USA) [33]. An in vitro cadaver RSA study support Saaris findings with the original Genesis II design (Smith and Nephew, Memphis, USA) [34].

Our approach, cementing both baseplate, stem, and stem canal creates a continuous mantle without hollow pockets, a well-established practice within total hip arthroplasty. Applying this technique to TKAs has been associated with reduced aseptic loosening in long-term follow-up of 988 knees over approximately 89 months [35]. Full cementing also decreased bone marrow contamination [36].

Opponents of full cementation argue that it alters force distribution at the bone-cement interphase, shifting loads distally to cortical cancellous bone, and potentially inducing stress shielding beneath the baseplate. This effect has been demonstrated in finite element analyses [16,34,37], though not consistently [38]. Stress shielding effects have not been clinically confirmed [39]. A recent *meta*-analysis found no direct correlation between stress-shielding and implant failure [40]. Furthermore, some authors contend that cementing the baseplate only is sufficient to prevent aseptic tibial loosening [41–43]. It may also better protect the bone stock, facilitating future revision surgery.

Cementing the stem of the tibial component to reduce aseptic loosening in TKA remains controversial as some clinical studies report decreased loosening rates while others find no significant benefit [43], suggesting that cementing the baseplate alone is sufficient. In another retrospective matched analysis, the authors found increased revision for FC-cemented knees due to mechanical failure, however not related to tibial failure [41]. A retrospective study by Sharkey and colleagues found more aseptic implant loosening with surface cementing technique [18]. Currently, no registry studies have investigated the impact of cement placement, as this data is not collected. For studying the long-term effects of cementing techniques, collecting such data would be insightful.

Collectively, these factors suggest that the influence of cementing technique on tibial migration is design- and context-dependent. Grupp et al. who evaluated tibial components with different keel and stem geometries and lengths in a posterior-stabilizing design in humans cadaver tibia and found similar results of FC and SC tibias [29]. The discrepancy with our findings may reflect implant design, loading regime, and measurement sensitivity when assessing whether cementing strategy affects early tibial stability in a meaningful way.

### *5.2. Bonding strength*

Push-out testing showed that full cementing of both baseplate and stem resulted in significantly higher initial bonding strength between implant and cement, an area known to be susceptible to implant loosening [22]. These findings align with previous studies using similar experimental setups [44]. Furthermore, comparison with pull-out testing, where the force is applied directly to the implant-cement interphase, between cementing techniques revealed greater bonding strength when the stem was cemented [45].

Overall, these findings indicate that cementing both baseplate and stem enhances initial implant-cement bonding, consistent with our findings.

### *5.3. Amount of cement and initial stability*

Findings from the current study indicate that cement mantle thickness counteracts micromotion of the implant, thus increasing the initial stability. Thicker cement mantle was achieved when using a full cementation technique. Due to hydrostatic back pressure increasing with increasing cement viscosity, cement has nowhere to go as it cures. This leads to cement flowing where the resistance is lowest, which was anterior in our setup. For the SC group, there was enough room to accommodate the increasing pressure, leading to less overflow of cement. This observation illustrates that levelled cement distribution is challenging, even in a simplified in vitro model and none the less in a clinical setting. From a biomechanical perspective, both techniques were applied under standardized conditions using identical inserts and baseplates, cement properties, sawbones properties, and loading protocols. The systematic difference in cement thickness reflects a reproducible outcome of the cementing strategies rather than uncontrolled experimental variability. Importantly, this distinction aligns with prior experimental and retrieval studies demonstrating that cement mantle continuity and thickness beneath the tibial baseplate are critical determinants of implant micromotion and debonding [5,13,44], regardless of whether these characteristics are considered a result of technique or cement handling.

This leads to the open questions: is micromotion reduced by increased cement thickness or extra cement around stem? Recently, a case-control study found that implants that failed due to aseptic loosening had significantly thinner cement interphase thickness both under the baseplate and around the keel [46]. Mikashima and colleagues found bone mineral density do be a determining factor in achieving sufficient cement mantle thickness in their randomized controlled trial [47]. A literature review by van Otten and colleagues found that thicker cement mantle beneath the tibial baseplate reduced aseptic loosening [48]. A retrieval study by Kutzner et al. showed decreased odds for aseptic loosening by 61% per mm increase in cement thickness [5]. Less than 1.5 mm of cement penetration into cancellous bone usually leads to higher radiolucency and lower tensile strength. This is associated with early implant micromotion [49–51]. In an in vitro study, Bert and McShane argue that FC had superior stability to SC when the cement mantle was 1 mm, but techniques were comparable when cement mantle had sufficient thickness of 3 mm[52].On the contrary, Tian et al. found increased cement mantle thickness to be a risk factor of developing radiolucent lines [53]. However, radiolucent lines are common postoperatively to TKA, but do not necessarily indicate risk of aseptic loosening [54]. Currently there is limited literature investigating the effect of the appropriate cement mantle thickness with respect to reducing aseptic loosening in TKAs. A general recommendation is to strive for at least 2 mm cement mantle thickness and a penetration depth between 3–5 mm [50,55]. Our present findings do not allow separation of the independent effects of cement placement location (stem versus baseplate only) from those of cement mantle thickness. Future studies designed to equalize cement mantle thickness across cementing techniques, or to manipulate mantle thickness independently, would be required to disentangle these interrelated factors.

### *5.4. Timing of cement application*

In our setup we decided to apply cement to the baseplate when the bone cement was in a sticky phase. Cement application in this phase is recommended by both Zimmer Biomet, manufacturers of the NexGen Stemmed Option baseplate [12], and DePuy Synthes who recommend application “while cement is still tacky” [11]. Applying cement this early is meant to enhance implant-cement bonding, as shown in in vitro settings [10,44]. Park and colleagues demonstrated that delayed mating of cement interfaces between implant and bone decreased the cement-cement interface bond, and got weaker with longer delay [56]. A review by Paul and colleagues suggested applying cement to the baseplate just when the cement enters the doughy phase, arguing that earlier application makes the cement flow away and more susceptible to mixing with blood [57].

Currently, there are no clinical studies assessing cement application timing with respect to baseplate loosening. Further studies are needed to evaluate the optimal timing in vitro.

### 5.5. Strength and limitations

This study design allowed isolation of a single variable- cementing technique, reducing confounding factors. We assessed micromotion and migration under simulated gait conditions, which are clinically relevant outcomes from a biomechanical perspective. The experimental setup was based on established methods [21,58]. Finally, the bone model has less variability than cadaveric bone and replicates the anatomical and mechanical characteristics of trabecular bone. The bone model is widely used in biomechanical research [23,59].

Despite the strengths of our study, it also has some limitations. First, it was conducted in an in vitro environment, which does not account for biological interactions. The cancellous sawbone model lacked an open porous structure, preventing assessment of deep cement penetration, an integral part of fixation clinically. Because a closed–pore composite bone model was used, cement penetration and cement-bone interdigitation could not be assessed. Our findings therefore reflect implant–cement mechanics rather than true cement–bone fixation.

Another limitation of the present study is that only one tibial implant design was evaluated. Accordingly, the findings primarily reflect the interaction between cementing technique and the specific design features of the NexGen Stemmed Option tibial component. While the biomechanical principles related to cement mantle continuity and stem fixation may be broadly applicable to cemented stemmed tibial components, the results cannot be directly generalized to all tibial designs, particularly cementless or highly porous implants.

Additionally, difference in anterior and posterior cement thickness in the FC group caused posterior inclination of the baseplate, likely resulting in uneven load distribution during cyclic testing. As the femoral condyles slipped posteriorly, the loading point shifted (in the same direction), leading to increased lift off anteriorly and more subsidence posteriorly. Migration in the present study is reported as signed values, distinguishing between anterior lift–off (positive displacement) and subsidence (negative displacement). While this approach provides directional information relevant for understanding load transfer and construct behaviour, it also complicates interpretation when comparing groups, as differences in direction do not necessarily reflect differences in the magnitude of total motion.

The loading protocol applied in this study comprised 20,000 gait cycles, corresponding to approximately 2–3 week of walking [60]. Consequently, the present findings reflect very early postoperative mechanical behaviour rather than long term fixation performance. Although early migration and micromotion have been shown to predict later aseptic loosening in radiostereometric analysis (RSA) studies [8], this association is indirect and probabilistic rather than determinative. Therefore, the results should not be interpreted as direct evidence of improved long term implant survival or reduced risk of clinical aseptic loosening.

The sample size was small ($n = 5$), but comparable to previous in vitro studies (and sufficient for statistical power) [44,61]. However, the results must be interpreted with caution taking the risk of type II error into account. The implant used (NexGen Stemmed Option) was drawn from the market due to loosening issues with PS femoral components and PS tibial inserts [25], although the PMMA-coated stemmed version (NexGen Stemmed Precoated) remains widely used in Norway [1].

## 6. Conclusion

We found that cementing both the stem and baseplate of the tibial component resulted in less micromotion of the baseplate, which is a mechanical protection against tibial debonding. Bonding strength was significantly higher when both baseplate and stem were cemented. A thicker cement mantle protected against micromotion of the implant, enhancing initial stability. However, these findings reflect short–term mechanical behaviour and were influenced by differences in cement mantle characteristics, construct stiffness, and experimental alignment. Given the use of a single implant design, a composite bone model, and limited loading duration, the results should be interpreted cautiously and cannot be directly extrapolated to long–term clinical performance.

Further studies comparing different baseplate designs with a similar experimental set-up are necessary to quantify the influence of cementing techniques on different types of tibial components. Comparing surface cementation to full cementation in clinical trials and registry studies are necessary to gain a better understanding of the long-term outcome of two techniques.

Under the specific experimental conditions tested, full cementation of the NexGen Option Stemmed tibial component was associated with reduced anterior micromotion and greater overall fixation compared to surface cementation.

## CRediT authorship contribution statement

**Michelle Khan:** Writing – review & editing, Writing – original draft, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Irene Ohlen Moldestad:** Writing – review & editing, Data curation. **Peter Ellison:** Writing – review & editing, Supervision, Methodology, Data curation, Conceptualization. **Jan-Erik Gjertsen:** Writing – review & editing. **Paul Johan Høl:** Writing – review & editing, Supervision, Project administration, Methodology, Conceptualization. **Ove Nord Furnes:** Writing – review & editing, Conceptualization.

## Funding

This study was funded through The Medical Student Research Programme at the Faculty of Medicine, University of Bergen.

## Declaration of generative AI use

Generative AI has been used to reformulate chapter 5.6 "Strength and limitations". The contents of the generated text have been verified by authors.

## Declaration of competing interest

None of the authors declare any competing interests that may influence the findings of this paper.

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