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ORIGINAL ARTICLE

Do cement pockets prevent fluid contamination of the undersurface of tibial baseplates?

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ABSTRACT

Background: Aseptic loosening remains one of the most frequent causes of implant failure following primary total knee arthroplasty (TKA). Prior literature has established that these failures appear to occur at the implant-cement interface—likely secondary to lipid contamination. Implant manufacturers have incorporated cement pockets on the undersurface of tibial implants to improve fixation.
Aim: The study aimed to determine if cement pockets prevent lipid contamination of the implant-cement interface.
Methods: A contemporary total knee tibial baseplate has recently incorporated cement pockets on its implants. We modeled clear acrylic tibial baseplate molds of this implant with and without cementation pockets. We then simulated an experimental cementing process with the introduction of lipids at the implant-cement interface. The surface area contamination at this interface was quantified using ImageJ software and presented as a percentage of the total baseplate surface area available for fixation.
Results: For the predecessor implant design without cementation pockets, the average tibial baseplate lipid contamination was 42.82%. The average tibial baseplate lipid contamination was 30.36% for the contemporary implant design with cementation pockets. The addition of cement pockets was found to significantly reduce lipid contamination ($p = 0.0265$).
Conclusion: Lipid contamination of the implant-cement interface remains a primary mechanism of implant failure following primary TKA. We found that the addition of cement pockets decreased the surface area of implant contamination with fluid. Therefore, while it is unclear whether cement pockets improve implant fixation, they do appear to reduce fluid/lipid contamination and alternative undersurface geometries and techniques should be considered to help prevent lipid contamination.
Relevance for Patients: Cement pockets and other undersurface designs may help prevent aseptic loosening, which has become a leading cause of revision surgery for persistently painful and/or unstable TKA in patients.

1. Introduction

The increasing demand for total knee arthroplasty (TKA) leads to a corresponding increase in TKA revisions [1]. Aseptic loosening remains one of the most common causes of TKA failure. A recent study demonstrated that aseptic loosening increased by 97% as the underlying indication for TKA revision from 2009 to 2014, with projections continuing to increase into 2030 [2].

The etiology surrounding the aseptic loosening of TKA is still debated. With the introduction of highly cross-linked polyethylene in 1998 and the use of modern implants, lysis-related failures have significantly decreased [3,4]. In contemporary practice, the implant-cement interface appears to be the "weak-link" of component fixation [5,6]. It

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is now accepted that both implant and surgical factors impact fixation [5,7-9]. More specifically, these include component malalignment, improper bone surface preparation, and drying, poor cement technique including mixing and handling, potentially high-viscosity cements, and smaller cement mantles, as well as other intraoperative surgical technique errors. These problems can all detrimentally affect the cement structure and strength at the implant-cement interface, potentially increasing the risk of component debonding and, subsequently, aseptic loosening [10-14].

In addition, we suspect that certain implant designs are more susceptible to lipid or fluid infiltration of the implant-cement interface, thereby posing an increased risk of aseptic loosening [5,9,15,16]. In fact, two popular implants have faced scrutiny for issues with tibial component loosening and subsequently incorporated design changes to improve fixation [15-20]. These redesigned tibial baseplates now include cementation "pockets" or "pits," while their predecessor implant designs primarily included only a keel and a peripheral baseplate rim (Figure 1). In theory, the addition of these pockets provides increased surface area for cementation. However, it is unclear whether these features also protect against lipid contamination of the tibial tray.

This study aims to assess the effect of cementation pocket additions to tibial baseplate designs on lipid contamination that naturally occurs on their undersurfaces during implantation. We hypothesize that the addition of cement pockets will decrease the total surface area of contamination. For comparison, we evaluated a recently redesigned implant that incorporated cement pockets against its predecessor design (without cementation pockets). We hypothesize that this updated component design with cementation pockets will have decreased lipid contamination compared to its predecessor design.

2. Methods

Two implant baseplates (contemporary and predecessor designs) were modeled. We assigned implant A as the predecessor implant without cementation pockets and implant B as the contemporary model with pockets. It should be noted that the contemporary design is not an exact replica of the modern implant due to difficulty modeling this implant with the undercut design features. Clear acrylic models were then constructed for each implant. Implant sizes were chosen specifically to ensure consistent surface area among implants. Rubber molds were constructed to match a line-to-line tibial preparation for the cementation of the tibial models (Figure 2). A white modeling dough was chosen with similar viscosity and appearance to the working phase of polymethylmethacrylate (PMMA). The decision to use modeling dough over PMMA was made to eliminate any potential confounding variables with PMMA, such as differences in viscosity, temperature, and timing of cement mixing.

Each implant was put through a simulated implantation using a standardized cementation technique. Specifically, "cement" was applied to the manufactured rubber mold and not applied to the backside of the implant. In each trial, before implantation, three drops of red contrast were applied to the top of the cement over the molded keel region to simulate lipid or fluid contamination that routinely occurs intraoperatively (Figure 3). The acrylic implant was then inserted and impacted until the implant was fully seated. When the implant was fully seated, the contrast that was dispersed between the implant and cement was easily visualized. Photographs were obtained from directly above the acrylic model. The simulated implantation was performed in triplicate for each implant and all images were collected for data analysis.

Images from each trial were then evaluated digitally utilizing ImageJ image processing software (version 1.54e; National Institutes of Health, United States of America [USA]). Lipid contamination was defined as the surface area of contrast

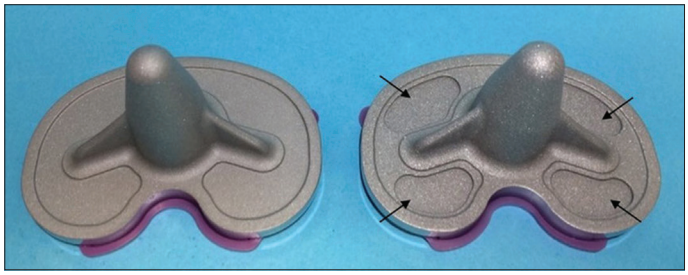

Figure 1. A predecessor implant without cement pockets (left) and the contemporary implant with cement pockets (right).

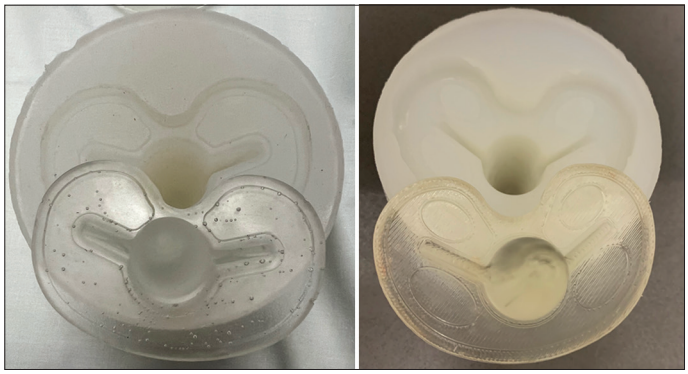

Figure 2. A predecessor tibial tray acrylic model without cement pockets (left) and the contemporary tibial tray acrylic model with cement pockets (right).

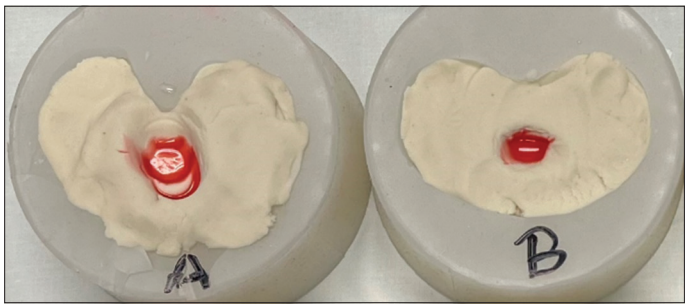

Figure 3. Predecessor implant (left) and contemporary implant (right; with cementation pockets) rubber models with dough and red dye before implantation with respective tibial baseplate acrylic models (represented in Figure 2)

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visualized under the baseplate and measured as the percentage of the surface area of the tibial tray that was involved. Given variable keel geometries and sizes between implants A and B, the area of the keel was subtracted from the area of the entire baseplate before the calculation of percent contamination (Figure 4). An image from each trial was measured by two authors (A.M. and W.G.), and these measurements were averaged for data analysis. Descriptive statistics were utilized to quantify the percent baseplate contamination by component type. Unpaired Student's *t*-tests were utilized to compare the difference in fluid contamination between baseplate designs. A $p < 0.05$ was considered statistically significant. Statistical analysis was performed using GraphPad (GraphPad Software, USA).

3. Results

Lipid contamination was notable in each trial implantation (Figure 5). The fluid appeared to distribute peripherally from the central keel area to the perimeter of the tray during implantation. For implant A (predecessor design without cementation pockets), the average tibial baseplate lipid contamination was 42.82%. For implant B (contemporary design with cementation pockets), the average tibial baseplate lipid contamination was 30.36%. The addition of cement pockets between implants A and B was found to significantly reduce lipid contamination ($p = 0.0265$) (Figure 6 and Table 1).

4. Discussion

Methods for improving tibial implant fixation can involve surgical techniques, patient selection, and implant designs. Some previous design changes include alteration of the tibial keel, peripheral rim, and roughened backsides. Recently, two contemporary total knee implants have been redesigned to potentially improve tibial implant fixation by incorporating cementation pockets [15-20]. While cement pockets increase the surface area for fixation, their ability to improve fixation has yet to be demonstrated. In addition, there has been an increased emphasis on improving implant-cement interface fixation as a method of decreasing aseptic loosening [14]. Specifically, decreasing lipid contamination of the tray undersurface appears to be a key target for decreasing implant loosening. The primary finding of our current study was that the addition of cement pockets did decrease the amount of lipid contamination of the implant-cement interface.

Aseptic loosening remains a common reason for revision following primary TKA, despite improvements in implant design and surgical techniques [1]. In fact, it is currently one of the leading causes of revision knee surgery, with a comparable incidence to periprosthetic joint infection [2]. Previously, aseptic loosening was predominantly an osteolysis-related failure secondary to polyethylene wear. With contemporary polyethylene and improved locking mechanisms, osteolysis-related failures following primary TKA are extremely rare. Despite this, interestingly, aseptic loosening remains one of the primary modes of failure [3,4]. A recent study demonstrated that 94% of failures occurred at the implant-cement interface, and failure at the bone-cement interface was uncommon [5]. Therefore, aseptic loosening primarily results from a failure of fixation at the implant-cement interface.

Implant-cement interface fixation is dependent on several factors. Surgical factors have previously been explored and can significantly alter implant fixation. Martin *et al.* recently demonstrated that implant fixation was significantly reduced when the knee was moved during the curing phase of cementation [9]. In addition, they demonstrated that there were significant differences among the implants, with and

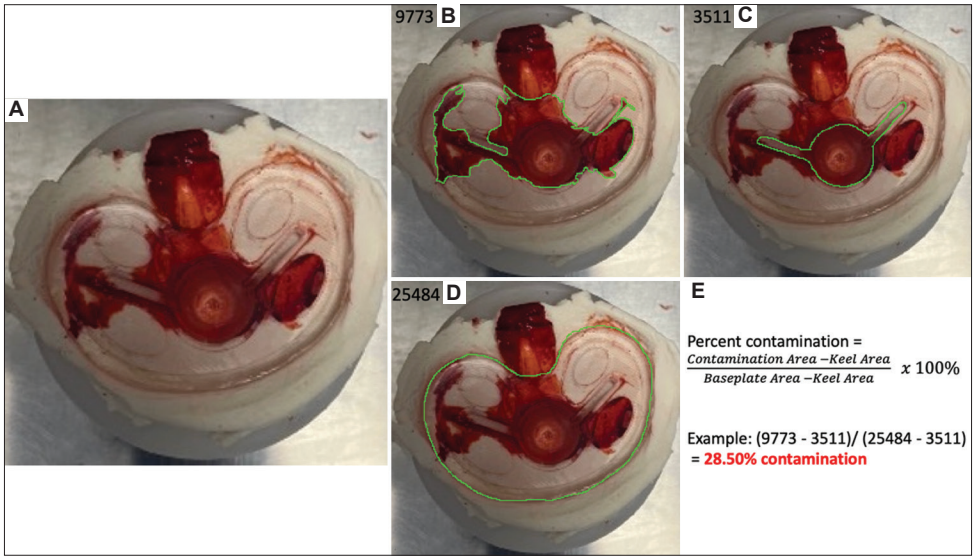

Figure 4. Calculation of tibial baseplate contamination. (A) Sample tibial baseplate following simulated implantation with red dye contamination using ImageJ image processing software. The total sum of baseplate contamination with red dye (B, outline in green) excluding keel surface area (C, outline in green) divided by total baseplate surface area (D, outline in green) was measured to calculate percent contamination (E).

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without motion. Therefore, undersurface geometry and surface roughness appear to be important factors in improving fixation at the implant-cement interface as well. An additional noteworthy finding from their study was the inverse correlation between lipid contamination of the tibial tray and implant fixation. Specifically, increasing the surface area of the tibial tray that was contaminated with lipids correlated with decreased implant pull-out strength. Therefore, we hypothesize that limiting the amount of contamination of the undersurface of the tibial tray should theoretically improve implant fixation.

Additional factors known to negatively impact implant fixation include component malalignment, improper bone surface preparation and drying, poor cement technique including mixing and handling, potentially high viscosity cements, and smaller cement mantles, as well as other intraoperative surgical technique errors [10-14]. In addition, PMMA, a biologically inactive substance that forms through a chemical reaction, has numerous potential aberrations that can compromise its strength and stability when used in the clinical setting for TKA [10-12].

Billi *et al.* recently explored a variety of cement techniques, evaluating the timing of bone cement application, as well as lipid contamination. They noted that early cement application significantly improved implant fixation and that lipid contamination led to a significant reduction in implant fixation. They demonstrated that cement application to both bone and the implant with a "double-butter" technique significantly improved implant fixation when lipids were introduced into the fixation interface [21].

We have recently demonstrated a potential mechanism for this finding. In a previous study, we evaluated seven contemporary tibial implant designs and observed that lipid contamination commonly occurred at the implant-cement interface when only the tibial surface had cement coating. However, with the double-butter technique, the amount of tray contamination approached 0% contamination for every implant, with a significant reduction noted for each implant. Interestingly, there were significant differences among the various implants' surface area contamination suggesting that tibial undersurface geometries can also affect lipid contamination [22].

Our prior double-butter study led us to explore whether cement pockets significantly reduce lipid contamination of the implant-cement interface in this study. Interestingly, the surface area of lipid contamination did significantly decrease with the introduction of cement pockets to the tibial baseplate. The current tibial implant design shares similar undersurface geometries, including a peripheral rim and a keel or stem. The peripheral rim is a design feature that allows for cement pressurization into bone. As the peripheral rim is inserted into the cement, fluid is trapped under the tibial tray and is then dispersed along the implant-cement interface. The undersurface addition of cement pockets did mitigate this dispersion, and in our study, we found that the cement pockets were often filled with fluid (Figure 7).

While this study appears to be the first to demonstrate that lipid/fluid contamination is influenced by the addition of cement

Table 1. Tibial baseplate fluid contamination following simulated implantation

Evaluation	Fluid contamination (%)	
	Implant A	Implant B
Trial 1	55.315	31.83
Trial 2	37.025	23.575
Trial 3	36.125	35.685
Average*	42.82	30.36

Implant A has no pockets; implant B has pockets; *p-value of the average is 0.0265.

Figure 5. Example of implant A (left) and implant B (right) after undergoing trial implantation

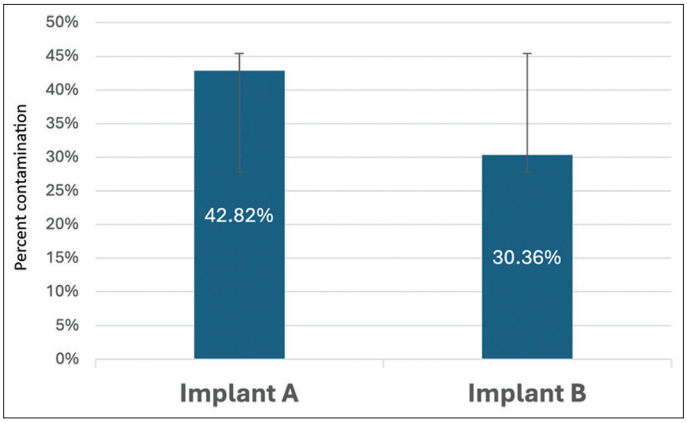

Figure 6. Average tibial baseplate fluid contamination following simulated implantation between implants A and B (p=0.0265)

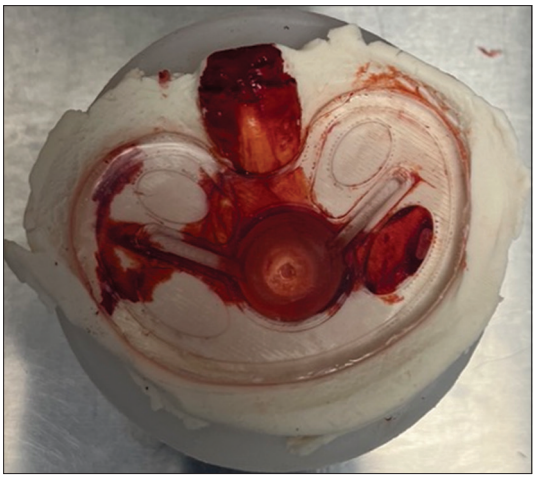

Figure 7. A baseplate trial demonstrating the filling of a cementation pocket with fluid

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pockets, there were several notable limitations. First, this was an experimental model with inherent design limitations. The fluid characteristics were meant to mimic what potentially happens during surgery, but the volume and location of fluid may not be representative. Second, the material properties of acrylic are not the same as cobalt-chromium or titanium. However, we still believe that the propagation of fluids at the implant-cement interface behaves similarly, whether PMMA bone cement or modeling dough is being tested. In addition, a direct correlation between aseptic loosening and lipid contamination remains somewhat theoretical. Methods for detecting lipid contamination are not currently available; therefore, determining direct causation remains elusive. Finally, while we believe that cementation pockets will lead to improved fixation strength by decreasing fluid contamination under tibial baseplates, we recognize that our study model does not assess this outcome or any other potential detrimental effects of tibial undersurface geometry changes, such as mechanical failures [23].

5. Conclusion

The addition of cement pockets in a contemporary TKA tibial baseplate was associated with a significant reduction in lipid contamination compared to its predecessor design without pockets. Our study demonstrated that approximately 30 – 40% of the tray can be contaminated with only three drops of fluid. Improvements in cement techniques could help limit lipid contamination of the tibial tray, while current tibial implant design features may reduce lipid dispersion at the implant-cement interface.

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Conflicts of Interest

The authors declare no competing interests.

Ethics Approval and Consent to Participate

Not applicable.

Consent for Publication

Not applicable.

Availability of Data

Data are available from the corresponding author upon reasonable request.

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