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Novel Application of 3D Printing to Development of a Homemade Posterior-Stabilized Knee Cement Spacer

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Abstract

Background: Articulating spacer facilitates reimplantation in two stage revision for knee periprosthetic infection. However, despite the prevalence of posterior stabilizing prostheses, most commercial prefabricated spacers are cruciate retaining with the problem of sagittal instability. This study reported the design and use of a novel intra-operatively molded, posterior stabilizing spacer developed in hospital setting using 3D printing technology.

Method: The design began with analysis of our hospital joint registry to identify commonly used models and sizes. Features of the 4 most commonly used models were incorporated into the design of the new spacer using computer aided design software. Three sets of dimensions were identified to form the 3 sizes of the new spacer. The prototype was output with 3D printing for producing mold for intra-operative use.

Case Report: A 68 years old lady was suffering from recurrent periprosthetic infection 6 months after right total knee arthroplasty. Two stage revisions were performed with the new spacer. Post-operative X-ray showed optimal fitting with the absence of posterior sagging.

Conclusion: The 3D printing technology has enabled the domestic development of cement spacer with personalized design, minimal inventory and improved stability.

Keywords: Periprosthetic infection; Knee; Arthroplasty; Spacer; Computer aided design; 3D printing

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Introduction

Although there have been continuous advancement in surgical techniques, periprosthetic infection remains one of the most challenging complications of total knee arthroplasty. It is the commonest cause of revision within first 2 years post-operation [1]. Two stage revisions have the highest success rate in eradicating infection and remains the gold standard of management [2]. In the interim period, the use of articulating spacer is recommended to preserve motion and facilitate reimplantation [3]. However, most prefabricated spacers in the market are cruciate retaining despite of the prevalence of posterior stabilized prostheses [4,5]. The association between sagittal instability and compromised functional outcome has been reported [6].

Shortage of posterior stabilized spacers in the market is due to diverse designs of cam post mechanism. However, in hospital setting, it is feasible to design a posterior stabilized spacer that is compatible to a limited number of models. In this article, we will demonstrate the design and application of a novel intra-operatively molded, posterior stabilized cement spacer developed in hospital setting using 3D printing technology.

Method

The design process initiated with analysis of our local joint registry to identify the most commonly used models. It recorded 2,948 knees in the past two decades. It was shown that the four most commonly used models were PFC (DePuy Synthes, Raynham, Massachusetts, USA), Triathlon (Stryker, Allendale, New Jersey, USA), Nexgen (Zimmer, Warsaw, Indiana, USA) and Legion (Smith and Nephew, Memphis, Tennessee, USA). All were posterior stabilized prostheses. Their cam post mechanism designs were analyzed. To ensure versatile fitting into their bone cut morphology, the lowest profile dimension from different models were identified and incorporated into the design of new spacer. As a result, the anteroposterior dimension of intercondylar box was adapted from Legion and proximal-distal dimension from Nexgen. The tibial keel was preserved to improve stability. The shape was adapted from Triathlon and the diameter was from Legion.

The dimension of the new spacer was then defined. For femoral component, it was defined by anteroposterior dimension of bone cut to ensure optimal fitting. For tibial component, it was defined by mediolateral dimension to reduce overhang. The range of prosthesis size was first identified from our registry. The 3 sets of dimension that can provide optimal coverage on the sizing range were identified and chosen as the dimension of the new spacer. The information was summarized in a sizing chart to facilitate pre-operative matching.

With the geometry and dimension defined, the development process was continued by prosthetist of our hospital. They are experienced in computer aided design gaining from amputee prosthesis fitting. Computer model of the new spacer was produced using SolidWorks (Dassault Systèmes, France). For femoral component, single radius design was used for its simplicity. It was made side nonspecific by tuning the anterior flange symmetrically to minimize inventory. For tibial component, symmetrical design was used. The lowest profile features from different models previously identified were integrated. To ensure compatibility between femoral and tibial components, the computer model was animated for motion analysis. The curvature of articulating surface and the position of cam post mechanism were adjusted to ensure congruency in full range of motion.

The prototype was exported and verified using 3D printing. The finalized 3D models were then used as a positive mold, from which the definitive negative molds were created. The positive mold was immersed with liquid silicone, which solidified over time. It was sliced into two halves before it was used as definitive mold for forming cement spacer. At last, hydrogen peroxide plasma sterilization was carried out for it to be ready for intraoperative use.

Case Presentation

A 68 years old woman, with known medical history of diabetes mellitus, had undergone right total knee arthroplasty. The prosthesis model used was Triathlon with both femoral and tibial component being size 3. She suffered from early post-operative infection on day 21 after operation. Debridement and insert exchange were performed. Intra-operative culture of synovium showed the presence of methicillin resistant *Staphylococcus aureus*. She was treated with antibiotics vancomycin for the duration of 6 weeks whilst her erythrocyte sedimentation rate and C-reactive protein were normalized.

Six months after the initial operation, she presented with recurrent painful swelling. Arthrocentesis yielded frank pus. Two stage revisions were undergone using the new spacer. During operation, the spacer was prepared on a sterilized table while implant removal was underway. Two bags of Simplex P with Tobramycin (Stryker, Allendale, New Jersey), was mixed with 4 gm of vancomycin powder during curling. The cement was applied into the mold after becoming doughy and was allowed to set with the mold recoupled. When excessive cement was trimmed off, the spacer was ready for use. During application, the bone-spacer interface was filled with additional cement to improve fixation. Intra-operative range of motion of 0° to 100° was achieved. Post-operative X-ray showed optimal fitting with the absence of posterior sagging.

Discussion

According to Philadelphia Consensus, articulating spacer is preferred over static spacer in two stage revision. It facilitates reimplantation by preventing soft tissue contracture and bone loss. However, complications have been reported with instability being the commonest [3]. In periprosthetic infection, ligaments are at risk due to infectious process and iatrogenic injury. The stability is further compromised if a cruciate retaining spacer is used after removal of a posterior stabilized prosthesis. Lanting et al. [6] reported a series of 72 cases with knee periprosthetic infection managed with cruciate retaining prefabricated molds or preformed spacers. Anteroposterior subluxation was found in 81.9% of cases. The functional outcome of subluxed group was inferior to that of the non-subluxed group. Therefore, a posterior stabilized spacer is necessary.

Despite the prevalence of posterior stabilized total knee arthroplasty, most commercial prefabricated molds [4,7] or preformed spacers [4] are cruciate retaining. The paucity of posterior stabilized spacer is due to the difficulty in creating a universally compatible design given the diverse cam post mechanism of contemporary prostheses. Shen et al. [8] illustrated a method to replicate the geometry of explanted prosthesis intra-operatively to form a posterior stabilized spacer. Cement was first applied around the explanted prosthesis. After hardening it became a mold from which the spacer was created. The method required the intra-operative production of the mold in addition to the spacer which was time consuming. Kohl et al. [9] illustrated the use of a preformed aluminum mold based on a single implant design. However, given the multitude of prosthesis models used in most centers, the inventory would be enormous. To take care both of inventory and versatility, the best solution is to have a preformed mold with a single design compatible to the local prosthesis profile.

Computer-aided design is defined as the use of computer systems to aid in the creation, modification, analysis or optimization of a design [10]. Its application in spacer design has not been previously demonstrated but it offers numerous advantages. Firstly, it enables accurate engineering of three-dimensional geometry. Features of local prosthesis can be freely incorporated with precision to ensure compatibility. Secondly, the components can be animated to simulate motion. Through motion simulation, the biomechanics of the design can be justified for restoration of motion and stability. Thirdly, the design can be easily modified to cater features of future prosthesis. With computer-aided design, both static and dynamic features can be optimized for fitness and function. The method is sustainable to the constantly changing profile of prosthesis in the future.

Reported applications of 3D printing in arthroplasty include fashioning of custom implant, patient specific jig and anatomical models for preoperative planning [11]. Our application in domestic development of cement spacer is firstly reported in literature. During the development of cement spacer, 3D printing allowed rapid production of prototype at a low cost. The prototype enabled confirmation of fitting, biomechanics and facilitated communication with surgeons. The verified model can be directly used as a positive mold to produce the negative mold for definitive use.

The aforementioned workflow was in the setting of a general hospital where we collaborate with our prosthetists. Their facility and expertise in 3D printing for amputee prosthesis fitting have been applied for development of the spacer mold. With gaining popularity of 3D printing and our simple workflow, it allows development of tailor-made spacer besides commercial companies.

The material in our intra-operative mold was silicone considering

its low cost and availability in most of the prosthetics and orthotics department. However, it is not the ideal material as its flexibility would result in uneven thickness of the spacer. Moreover, it is intolerable to high temperature sterilization thus it cannot be sterilized for more than once. After verification of the design and workflow, metal mold should be fashioned for recurrent use and consistent output.

To summarize, we have illustrated the novel application of 3D printing technology to domestic development of a cement spacer. Its design was customized to local prosthesis profile, with minimal inventory and enhanced stability. The workflow was applicable to general hospital setting with access to 3D printing facilities.

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