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REGULAR ARTICLE

Constructing a 3D-printable, bioceramic sheathed articular spacer assembly for infected hip arthroplasty

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Abstract Total hip arthroplasty (THA) has progressed to be one of the most cost-effective surgical procedures to relieve pain and restore function to the pathological hip. Official retrospective statistics revealed over 500,000 cases of THA were performed per annum in the US alone, but failure cases brought about more than 40,000 revision procedures among them. The revision surgery is usually hard to manipulate due to the formidable difficulty of repairing the critical bone defect. Plenty of attempts aiming at tackling this problem have been dedicated by both tissue engineering and clinical investigators. Despite of the initial success, it is still a great challenge to overcome atypical intertrochanteric and diaphyseal defects of proximal femur to reach a satisfied therapeutic outcome in terms of long-term survivorship of the prosthesis. Given the interdisciplinary integration of biomaterial fabrication, bone tissue engineering, rapid prototyping, and biomacromolecule/drug delivery, we propose a hypothesis to construct a biphasic articular spacer to reach the dual goal of infection control and bone regeneration in this study. To be specific, this complex is consisted by a geometry-specific calcium phosphate sheath, derived from computer aided design and low temperature 3D printing, and an axial bone cement pillar delivering antibiotics. Theoretically, this modularized spacer possesses the potency of enhanced osteogenesis, controlled release of specific drugs, and co-delivery of growth factors. If this strategy is validated, further effort can be made to strengthen the printability of calcium phosphate using the 3D printing technique, and to accelerate its translation from lab to clinics.

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Introduction

Total hip arthroplasty (THA) is one of the most successful surgical procedures performed nowadays, with excellent clinical outcomes showing over 95% and 80% implant survivorship at 10- and 25-year follow-up, respectively [1]. For patients with hip problems due to a variety of conditions such as osteoarthritis, osteonecrosis, developmental dysplasia of the hip, and femoral neck fracture, etc., THA can relieve pain, restore function, and improve quality of life significantly, by replacing or resurfacing the compromised bone and cartilage tissue with a prosthesis mostly referred to as a "ball and socket" assembly (Fig. 1a). It is estimated that more than 1 million THA are performed worldwide annually, and this number is projected to double within the next two decades [2].

Despite of the prominent improvement, periprosthetic infection is still an increasing and devastating complication that results in increased morbidity, mortality, and healthcare waste. Analysis of US Medicare data has shown a rate of periprosthetic infection of 1.67% at 2 years and 0.59% at 10 years, which is similar to the data from the European and Australian joint registries [3]. Once periprosthetic infection occurred, several well-established treatments are mandatory in case of serious sequel. The vast majority of treatments include a re-operation called "revision" and a course of specific antibiotics targeting the pathogen (mostly *Staphylococcus aureus* and *Staphylococcus epidermidis*). The revision surgery is usually a complete exchange of a hip replacement done in two stages: complete removal of the implant, debridement of the infection, and implantation of a temporary cement spacer at the first stage (Fig. 1b), followed by a 6-week course of intravenous antibiotics and re-implantation of a definitive hip prosthesis at the second stage.

One critical problem is that less host bone is usually available at the second-stage surgery, in view of multifactorial effects of stress shielding, osteolysis, failure of the implant, bone cement erosion, and infection (Fig. 1c). Further bone loss may be caused by removal of the infected prosthesis during the surgery. It was reported that diaphyseal defects of femur are found in 13–19% of revision cases [4]. These bone defects, especially in transtrochanteric area and the proximal diaphyseal of femur, can drastically impair the stability and long-term survival of the re-implanted prosthesis (Fig. 1d).

To the best of our knowledge, although the current antibiotic-impregnated bone cement spacer has been proved as efficient in eliminating the infection (less than 8% recurrence) [5], one deficiency during this anti-infection course is the negligence of bone defect repair. As a matter of fact, it

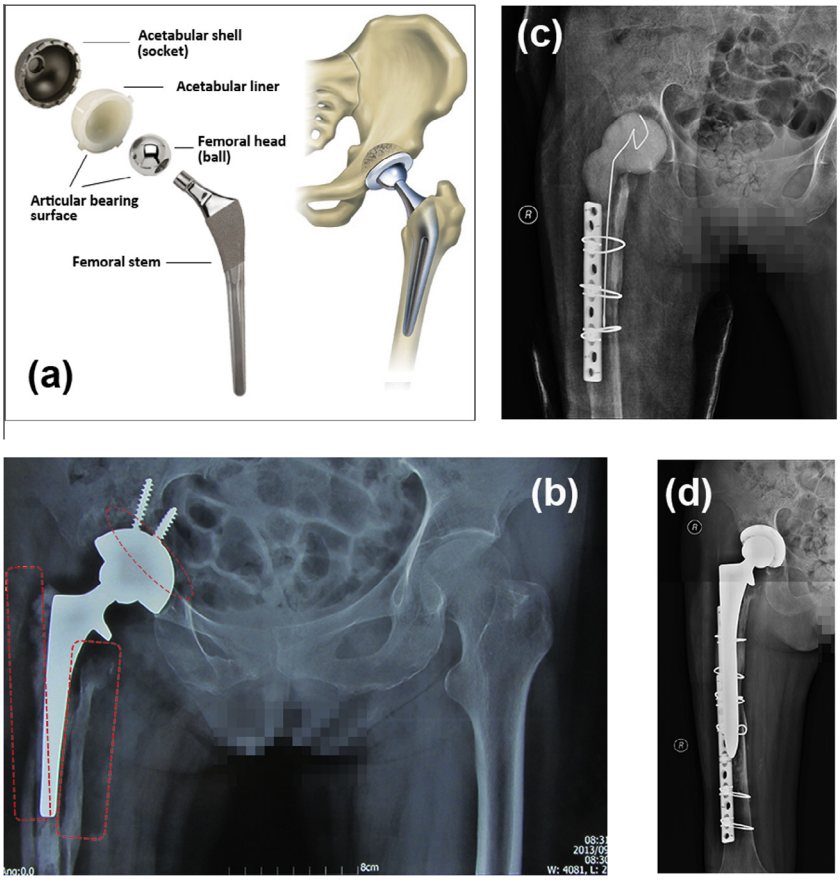

Fig. 1 Brief introduction of THA and its revision surgery. (a) The components of a set of arthroplastic prostheses. (b) A case report of a chronic periprosthetic infection three years after THA. Both the femoral and acetabular components failed with critical bone defect at the proximal femur (red lined region). (c) All the components were removed at the first stage of the revision, and a hip spacer was implanted in situ for the purpose of allowing partial motion, eliminating the infection and maintaining abductor tension. (d) After 6 weeks, the hip was reconstructed by DPF and extramedullary augmentation techniques at the second stage of revision.