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Variation of the impact duration during the in vitro insertion of acetabular cup implants

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ABSTRACT

The acetabular cup (AC) is an implant impacted into a bone cavity and used for hip prosthesis surgery. Initial stability of the AC is an important factor for long term surgical success. The aim of this study is to determine the variations of the impact duration during AC implant insertion.

Twenty-two bone samples taken from bovine femurs were prepared *ex vivo* for the insertion of an acetabular cup implant, following the surgical procedure used in the clinic. For each bone sample, ten impacts were applied using reproducible mass falls (3.5 kg) in order to insert the AC implant. Each impact duration was recorded using a wide bandwidth force sensor.

For all bone samples, the impact duration was shown to first decrease as a function of the impact number, then reaching a stationary value equal in average to 4.2 ± 0.7 ms after an average number of 4.1 ± 1.7 impacts. The impact duration may be related to variations of the bone–implant interface contact rigidity because of an increase the amount of bone tissue in contact with the AC implant.

Measurements of impact duration have a good potentiality for clinical application to assist the surgeon during the insertion of the AC implant, providing valuable information on the bone–implant interface contact properties.

1. Introduction

Hip arthroplasty is a common intervention in orthopaedic surgery. However, failures are still observed [1,2], leading to dramatic consequences for the patient. Among the different causes for surgical failures, acetabular cup (AC) aseptic loosening [3] and intra-operative bone fractures [4] have been described, especially in osteoporotic patients.

The AC is impacted in a cavity reamed in the native acetabulum, which generates circumferential tensile stresses in bone acting as an elastic band on the shell and generating circumferential compressive stress in the titanium metal back. The geometrical misfit between the reamed cavity and the implant shape leads to residual stresses responsible for the implant primary stability. Obtaining a strong primary implant stability is important because (i) the AC is rapidly loaded after surgery and (ii) the quality of implant secondary stability (related to osseointegration phenomena) depends on the implant primary stability [5].

The mechanisms involved in the long term attachment between the AC implant and bone tissue depend on the surgical technique [6]. Intra-operative use of the reamer may lead to a non-perfectly hemi-spherical hole and thus to a fixation of poor quality. When the hole in bone tissue is not perfectly hemi-spherical, the contact between the shell and bone may be imperfect, which decreases the quality of the fixation [7]. Increased bone stiffness, soft tissue entrapment and bone fragments are other possible mechanisms that may prevent uniform seating of the shell and generate non-uniform loading of the shell on bone tissue [8]. To avoid these problems, the surgeon generates several impacts with a risk of bone fracture if the load is too high [9]. Intra-operative methods to assess the implant primary stability and to determine cup seating currently rely on the surgeon's ability to estimate proprioceptively the evolution of the AC position in the bone cavity with subsequent impacts. More reliable and reproducible methods are needed to avoid AC aseptic loosening [10–12] and to allow bone ingrowth around the AC.

Some surgical strategies suggest using cement or screws to obtain implant primary stability [13–15]. However, the use of cement may lead to intra-operative risks [16], loss of time and to potential problems in case of implant revision. Another approach is to use the press-fit (cementless) technique which consists in

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slightly oversizing the cup compared to the cavity realized in acetabulum [17–20]. Moreover, the use of cement does not prevent from long term risk of aseptic loosening. Despite numerous studies on implant shapes [21,22], material [23,24] and porous coatings influence [25–28], the determinants of primary stability remain poorly established [29–31] because it is related not only to the surgical procedure, but also to bone quality and acetabular anatomy.

The use of medical imaging techniques has been proposed to study the stability of AC implants, such as magnetic resonance imaging (MRI) [32] and computed tomography (CT) [33]. However, both methods cannot be used intra-operatively to provide information about primary stability due to magnetic fields disturbance [34–36] and scattering of X-rays [37], respectively. Moreover, these two aforementioned techniques do not allow to retrieve information on the bone–implant mechanical contact conditions, which plays an essential part in the primary stability [38–41].

Most orthopaedic surgeons use empirical approaches (based on the surgeon proprioception such as pull-out tests [42] or impact sound variations [43,44]) to adapt and optimize their surgical strategy. However, the use of such empirical approaches lacks preciseness and accuracy and may in some cases lead to AC implant with insufficient primary stability (when the AC is not entirely and correctly inserted) or to bone fracture when too many impacts have been realized (especially in the case of osteoporotic patients). Based on the surgeon experience, an interesting study has investigated the frequency analysis of the hammering sound of the femoral stem, obtained with a microphone [44]. However, such technique does not allow to predict the level of primary stability of the femoral stem.

Biomechanical techniques have been developed to assess implant stability in the context of other types of endosseous implants. Methods based on resonance frequency analysis have been developed for femoral stem [9,45–47] and for dental implants [48]. Quantitative ultrasound techniques recently developed for dental implants by our group are used to measure the mechanical properties of bone–implant interface [49–52]. Interestingly, the Periotest (Bensheim, Germany) method is a percussion test based on the recording of the deceleration time of a metallic rode impacting a dental implant [53]. However, the aforementioned methods have been developed in the context of dental implants and it remains difficult to assess intra-operatively the AC primary stability during its insertion. The development of new biomechanical methods could help surgeons to determine how firmly the AC is seated, if they still need to hammer the AC implant, or if they have to stop impacting to decrease acetabulum fracture risks.

The aim of the present study is to investigate the variations of impact duration during the insertion of the AC implant. To do so, 22 bone samples taken from the distal and proximal parts of bovine femurs were considered. For each bone sample, ten impacts were applied under controlled conditions to insert an AC implant in dedicated cavities. The force between the mass and the impactor

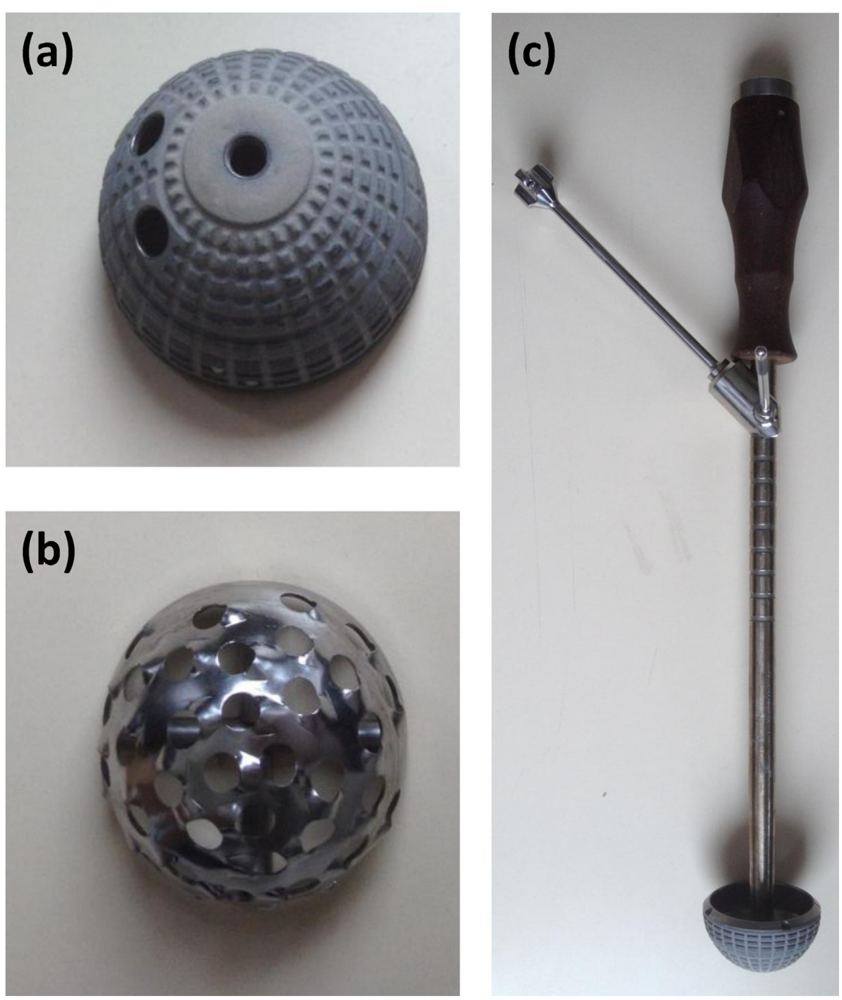

Fig. 1. Images of (a) the acetabular cup (50 mm diameter), (b) the reamer (50 mm diameter) and (c) the cup impactor (Ceraver, Roissy, France).