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Influence of different sizes of composite femora on the biomechanical behavior of cementless hip prosthesis

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ABSTRACT

Background: For the biomechanical evaluation of cementless stems different sizes of composite femurs have been used in the literature. However, the impact of different specimen sizes on test results is unknown.
Methods: To determine the potential effect of femur size the biomechanical properties of a conventional stem (CLS Spotorno) were examined in 3 different sizes (small, medium and large composite Sawbones®). Primary stability was tested under physiologically adapted dynamic loading conditions measuring 3-dimensional micromotions. For the small composite femur the dynamic load needed to be adapted since fractures occurred when reaching 1700 N. Additionally, surface strain distribution was recorded before and after implantation to draw conclusions about the tendency for stress shielding.
Findings: All tested sizes revealed similar micromotions only reaching a significant different level at one measurement point. The highest micromotions were observed at the tip of the stems exceeding the limit for osseous integration of 150 μm. Regarding strain distribution the highest strain reduction after implantation was registered in all sizes at the level of the lesser trochanter.
Interpretation: Specimen size seems to be a minor influence factor for biomechanical evaluation of cementless stems. However, the small composite femur is less suitable for biomechanical testing since this size failed under physiological adapted loads. For the CLS Spotorno osseous integration is unlikely at the tip of the stem and the tendency for stress shielding is the highest at the level of the lesser trochanter.

1. Introduction

In vitro investigations represent a decisive part in preclinical testing of cemented and cementless implants (Gheduzzi and Miles, 2007; Scheerlinck and Casteleyn, 2006). In addition these examinations are useful for predicting the impact of different implant designs and biomechanical conditions like variation of offset and center of rotation in total hip arthroplasty (THA) (Bieger et al., 2012; Enoksen et al., 2014; Enoksen et al., 2016; Fottner et al., 2011; Wik et al., 2011).

There are two main mechanical investigation methods, the determination of surface strain patterns and the measurement of micromotion between bone and implant (Bieger et al., 2012; Bieger et al., 2013). The implantation of THA induces the alteration of strain distribution leading to bone remodeling processes. It is well known, that stems with diaphyseal anchorage lead to a decrease in bone density in the metaphyseal region of femoral bone also called stress shielding (Decking et al., 2006). Thus modern stem designs aim for proximal load transfer with less reduction of surface strain in this region (Gronewold et al., 2014).

The rationale for measuring the relative micro-movement at the implant-bone interface is based on animal studies that demonstrated the failure of osseous integration of cementless implants if movements exceeded 150 μm (Pillar et al., 1986). Differing methods to register those micromotions have been described (Bieger et al., 2013; Fottner et al., 2009; Østbyhaug et al., 2010). 3-Dimensional measurements with six degrees of freedom seem to be more precise than measuring axial displacement with a single degree of freedom (Gheduzzi and Miles, 2007).

There are two different main kind of specimen for biomechanical investigations of THA, fresh frozen cadaver bones and artificial composite femurs (Gheduzzi and Miles, 2007). Composite femurs have the advantage of identical anatomy and material properties making the results more comparable (Gronewold et al., 2014; Small et al., 2016). Due to different loading scenarios along with varying measurement devices and locations, comparisons of the experimental outcome of different research laboratories are very difficult (Gheduzzi and Miles, 2007). Additionally, different sizes of composite femurs, mainly medium and large Sawbones® (Pacific Research Laboratories, USA), have been used. But,

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to the best of our knowledge, the influence of different sizes of artificial femurs on biomechanical test results is unknown.

Therefore the aim of this study was to compare the primary stability and surface strain distribution of 3 different sizes of composite femurs after implantation of a cementless stem. In particular the question was to be answered whether the size of artificial femur has a decisive impact on biomechanical evaluations.

2. Method

2.1. Specimens and implants

To evaluate the influence of different specimen sizes 4th generation composite femurs (Sawbones® Pacific Research Laboratories, USA) were used (Gardner et al., 2010; Heiner, 2008). Tests were performed with six small (#3414), six medium (#3403) and six large (#3406) left composite femurs respectively. For the biomechanical assessments the clinically well-established and proven cementless CLS Spotorno stem (Zimmer, Warsaw, USA) was selected (Aldinger et al., 2009; Evola et al., 2014). According to the three different composite femurs three different sizes of CLS stems were used. For the small femur size 6, for the medium femur size 11.25 and for the large femur size 13.75 was applied. For all implants the neutral version with a neck angle of 135° was chosen.

2.2. Specimen preparation

All implantations were performed according to the official surgical technique. The femoral neck was resected 0.9 cm proximal to the lesser trochanter. After opening the femoral canal the composite femurs were stepwise prepared with increasing rasps beginning with size 5 until the appropriate size was reached. According to the different sizes of artificial femurs the cementless stem was placed with a distance of 10 mm, 15 mm and 20 mm from the shoulder of the implant to the tip of the greater trochanter.

After the implantation radiographs of all specimens were performed and the femurs were shortened and embedded in a metal pot using a polyurethane resin (Rencast FC 53, Gössl-Pfaff GmbH, Karlskron, Germany). Since the different stem sizes used led to altered load transfer to the artificial femurs the distance from the lesser trochanter to the level of embedment was adapted to the length of the stem from the shoulder to the tip of implant (Table 1). To obtain physiological loading conditions during walking according to in vivo data the specimens were placed with an adduction angle of 16° in the frontal plane and 9° flexion angle in the sagittal plane (Bergmann et al., 2001). All tests were performed with a standard 32 mm head with medium length. The load was applied to the head using a suitable ceramic liner, mounted to the actuator of the testing system via an x-y table to avoid possible shear forces in the transversal plane during testing.

Table 1
Length from lesser trochanter to embedment and adapted cyclic loads in adaption to the length of CLS stem for each specimen size.

Size of specimen	Small	Medium	Large
Size of CLS stem	6.0	11.25	13.75
Length of stem (from shoulder to tip)	139.3 mm	158.1 mm	167.1 mm
Relative length compared to CLS 13.75	83.3%	94.6%	100.0%
Length from lesser trochanter to embedment	191.6 mm	217.6 mm	230.0 mm
Adapted cyclic loads	250.0–1416.1 N	283.8–1608.2 N	300.0–1700.0 N

2.3. Micromotion registration

All three groups were initially intended to be loaded with the same conditions adjusted to the in vivo measurement data of a patient with a body weight of about 70 kg, walking on level ground (Bergmann et al., 2001; Damm et al., 2013). The planed dynamic loading cycles with amplitude between 300 N and 1700 N were already used in other biomechanical investigations performed at the same institute (Fottner et al., 2009; Fottner et al., 2011). But since the small composite femurs failed when reaching 1700 N the sinusoid dynamic load needed to be reduced. We decided to adjust the load to the length of the three different stems. The adapted loads for each size are displayed in Table 1. To compare the different sizes under the same loading conditions additional tests were performed with amplitude between 250.0 N and 1416.1 N. All loads were applied with a frequency of 1 Hz using a material testing device (ElectroPuls E10000, Instron, Norwood, USA). For preconditioning all specimens were loaded with this dynamical loading pattern for 10 min.

Micromotions were registered 3-dimensionally in 6 degrees of freedom with a resolution of 0.1 μm by 6 linear variable displacement transducers (LVDT) (HBM Weta 1/2 mm, Hottinger, Darmstadt, Germany) similar to former studies (Fottner et al., 2009; Fottner et al., 2011; Görtz et al., 2002; Thomsen et al., 2002; Nadorf et al., 2014; Pepke et al., 2014). The LVDTs were mounted on a quadrate rack in three-two-one configuration which was rigidly attached to the composite femur at the level of measurement. The LVDTs were directed to a cube rigidly fixed with a metal rod to the surface of the prosthesis (Fig. 1).

3-Dimensional registrations were performed at 6 measurement points. 3 points were located on the medial side (Aldinger et al., 2009; Bieger et al., 2012; Bühler et al., 1997) and 3 points on the ventral side (Bergmann et al., 2001; Bieger et al., 2013; Damm et al., 2013) of the specimen (Fig. 2a–c). The two proximal points (Aldinger et al., 2009; Bergmann et al., 2001) were situated at the level of the lesser trochanter and the two distal points (Bühler et al., 1997; Damm et al., 2013) 1.5 cm

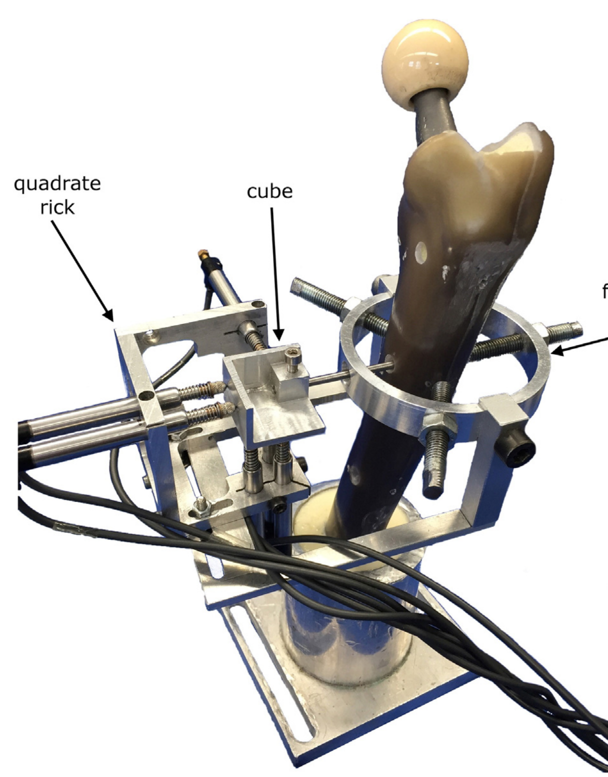

Fig. 1. Setup for the 3-dimensional micromotion measurement using 6 LVDTs aligned in 3-2-1 configuration to the inner cube fixed with a metal rod onto the surface of a CLS Spotorno stem at the point 4.