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ORIGINAL PAPER

Can the metaphyseal anchored Metha short stem safely be revised with a standard CLS stem? A biomechanical analysis

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Abstract
Purpose Short stem total hip arthroplasty (SHA) has gained increasing popularity as it conserves bone stock and is supposed to allow revision with a conventional stem. However, no study has evaluated whether the revision of a SHA with a standard total hip arthroplasty (THA) stem provides sufficient primary stability to allow osseous integration.
Methods A neck preserving SHA (Metha) and a standard THA (CLS) stem were implanted into six composite femurs respectively and dynamically loaded (300–1700 N, 1 Hz). Primary stability was evaluated by three dimensional-micromotions (3D micro motion) at five points of the interface. Then, a revision scenario was created by removing the SHA and using the same CLS stem as a revision implant (CLS-revision group), with subsequent evaluation of the 3D micro motion according to the primary CLS stem.
Results The 3D micro motion pattern significantly differed in the primary situation between the short and the standard stem. The highest 3D micro motion were registered proximally for the Metha and distally for the CLS stem. Revising the Metha with a CLS stem revealed a bony defect at the calcar. However, the 3D micro motion of the CLS-revision group were not significant higher compared to those of the primary CLS stem.
Conclusion Our results show, that SHA (Metha) and standard THA (CLS) provide a good primary stability, however with different pattern of anchorage. The CLS stem reached a similar stability in this revision scenario as the CLS in the primary situation, wherefore it can be assumed that in uncomplicated revisions the Metha short stem can safely be revised with a CLS standard stem.

Keywords Micromotion · Initial fixation · Anchorage · Three dimensional · 3D · SHA

Introduction

Short stem total hip arthroplasty (SHA) recently gained popularity and has been used with increasing numbers over the last few years [1, 2]. Multiple short stems designs from different manufactures have been introduced [3] as the initial results of the first SHA have been promising [2, 4–7]. Potential advantages for metaphyseal anchored short stem hip implants include a reduction in stress shielding [8, 9], less blood loss [10], and soft tissue damage due to the smaller and curved implant during implantation [3, 8, 11]. A further advantage is the preservation of bone stock which is supposed to facilitate revision procedures [3, 5] and enables the use of a conventional total hip arthroplasty (THA) stem should a revision become necessary [1, 5].

However, up to now there is still little evidence that metaphyseal anchored SHA implants can safely be revised to cementless standard stems. Only a few reports describe the revision of SHA with a conventional THA [1, 5], but no study has yet shown that a firm anchorage of a cementless standard stem can be achieved in such a revision scenario.

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The main reason for the lack of evidence is, that most SHA implants have only been introduced over the last few years and long-term results with noteworthy numbers of revision procedures are not available yet [1, 3]. In this context, it appears highly important to evaluate the mechanical behaviour and anchorage of conventional THA stems when used in revision scenarios of short stem hip arthroplasty.

Therefore, the aim of this biomechanical study was to evaluate whether an aseptic or uncomplicated failure of a metaphyseal anchored SHA stem can be revised with a standard THA stem. We hypothesized that a cementless standard THA stem can achieve sufficient primary stability in such a revision scenario to allow osseous integration.

Materials and methods

Implants

For SHA, a metaphyseal anchored short stem (Metha, B. Braun, Aesculap, Tuttlingen, Germany) was evaluated (Metha size 3, 135°) (Fig. 1). The stem is a cementless, partial collum sparing implant which is double tapered, collarless with a metaphyseal anchorage [5, 8]. The distal stem is polished and the top two-thirds are coated with a 0.35 mm micro-porous titanium and a 20 μm dicalcium phosphate coating.

For standard THA, a cementless proximal anchored standard stem (CLS, Zimmer, Warsaw, Indiana, USA) with proven good long term results was used (CLS size 13.25,135°) (Fig. 1) [12–14]. The stem is straight and collarless with a proximal anchorage. It has a rectangular cross-section with sharp proximal, anterior, and posterior ribs/flutes with a porous, grit-blasted titanium alloy (Ti6A17Nb alloy) surface.

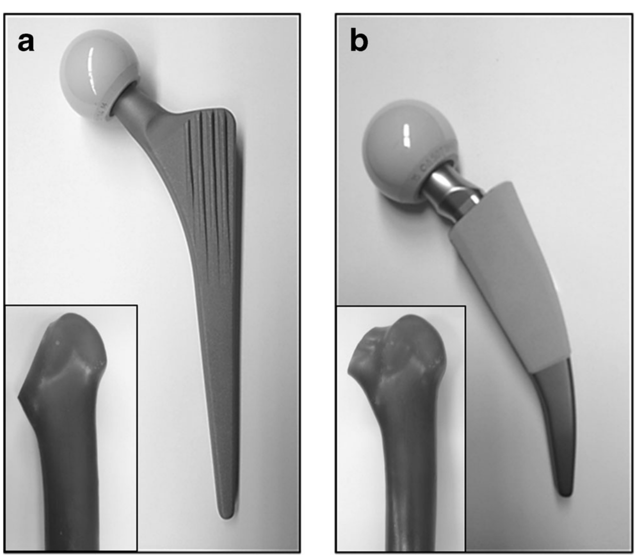

Fig. 1 **a**) Conventional THA stem (CLS, Zimmer-Biomet) with a standard osteotomy and **b**) metaphyseal anchored SHA stem (Metha, **b**. Braun, Aesculap) with a partial neck preserving osteotomy

Specimen preparation

Both implants, Metha SHA and CLS THA, were implanted into six composite femurs, respectively (Model 3306, Size L, left side, Sawbones Pacific Research Laboratories, USA). Implantation was performed by one orthopaedic surgeon (FS) under fluoroscopy according to the manufacturer's instructions. For the Metha stem a partial neck preserving osteotomy and for the CLS stem a standard femoral-neck osteotomy was performed (Fig. 1). The composite femurs were firmly embedded in a metal pot (Technovit 3040, Merck, Darmstadt, Germany) after cutting 20 cm below the lesser trochanter. To simulate a physiological loading condition according to the in vitro data of Bergman et al. the specimens were placed in an 16° adduction in the frontal and 9° posterior tilt in the sagittal plane [15].

Loading procedure

Specimens were loaded as previously described [16, 17] with a sinusoid dynamic load (1 Hz) and an amplitude of 300 to 1700 N. The testing parameters simulate a physiological load of a patient with 70 kg while walking on level ground [15]. The load was applied in the vertical downward direction using a hydraulic testing device (Schenck Process GmbH, Darmstadt, Germany), with the load transferred via a ceramic liner and a standard ceramic head (32 mm, size M). Implants were all preloaded for 10 min (600 cycles) prior to the first measurements.

Measurement under dynamic loading

3D micro motion were obtained as previously described by using a highly accurate test setup [16, 17] which is similar to the one originally published by Götze et al. [18]. Briefly, the unit registers micromotions in six degrees of freedom at the interface and consists of an outer rack (6×6×6 cm) and an inner cuboid (3×2×3 cm). The outer rack is designed to hold six linear variable displacement transducers (LVDT) (HBM Weta 1/2 mm, Hottinger, Darmstadt, Germany) in a 3-2-1 configuration (Fig. 2). It is rigidly fixed to the composite femur with a metal ring at the same level of the testing point to reduce errors from bone deformation. The inner cube has a metal rod which is firmly attached to the implant and transfers the micromotions from the interface to the cube. The micromotions of the inner cube are registered by the LVDT from the outer rack with a resolution of 0.1 μm. The specimens were preconditioned and every single point was measured for 30 cycles.

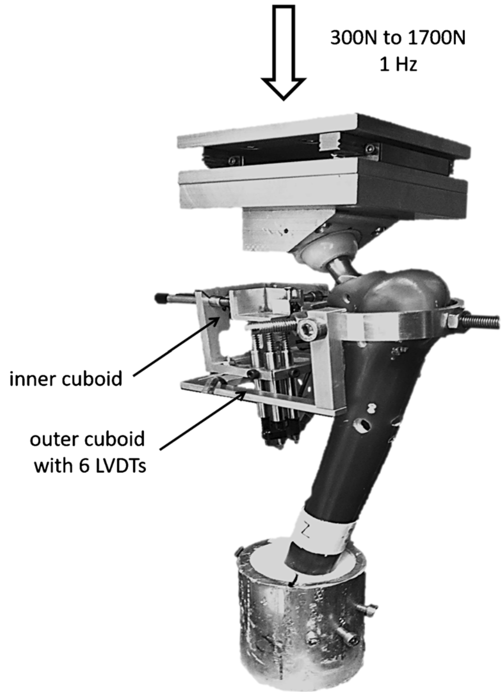

Fig. 2 Set-up configuration for measuring 3D–micromotions at the bone-implant interface. Composite femur (Sawbone) with a cementless THA, the outer cuboid with six LVDTs (3-2-1 configuration) is fixed to the bone at the level of the measurement point. The inner cuboid is fixed to the prosthesis over a metal rod

Primary setting (Metha and CLS stem)

In the primary implantation setting, five points (P1–5) were measured for both stems (Fig. 3): one medial (P1 = proximal-medial), three ventral (P2 = ventral-proximal, P3 = ventral-median, P4 = ventral-distal), and one lateral (P5 = distal-lateral). Due to the difference in the implant design in terms of size and shape the points of the SHA and standard THA do not correspond to the identical locations.

Revision setting (CLS and CLS-revision stem)

For the revision setting, the SHA was removed after measuring the 3D micro motion. Then the femur was prepared for the CLS stem as a revision implant. Preparation was performed as described for the primary CLS scenario with an osteotomy, stepwise broaching, and insertion of the same CLS stem (size 13.75). All measurements for the revision CLS (CLS-revision) stem were performed equally to those of the primary CLS stem, with the points corresponding to identical locations.

Data analysis

A coordinate system around the three planes of the inner cuboid was defined as a reference to calculate the micromotions in 6 degrees. The 3D micro motion were calculated using a custom software program written in MATHLAB (MathWorks, USA, Version R2013a.) as previously described [16] which uses the formulas as published by Görtz et al. [18].

Statistics and analysis

Data are given as mean ± standard deviation (SD). Statistical analysis and graphs were performed with GraphPad Prism 5 (GraphPad Software, Inc. La Jolla California, USA). After testing for normality with the Kolmogorov-Smirnov test, an unpaired Student's t test was used to compare the CLS vs. Metha stem in the primary scenario and the primary CLS vs. the CLS-revision stem in the revision scenario. A p-value <0.05 was considered to denote significance.

Results

All implantation and subsequent loading procedures were performed successfully without failures. No irreversible migration of the stems was observed for all groups after finishing the measurements. The results of the 3D–micromotions are displayed in Figs. 3 and 4.

Primary implantation (CLS and Metha)

In the primary scenario, major differences in the 3D micro motion between the Metha and CLS stem were observed according to their different anchorage philosophies (Figs. 3 and 4). Significant differences were found for the proximal points P1 and P2 (both $p < 0.0001$) as well as for the distal points P4 ($p = 0.002$) and P5 ($p < 0.0001$). No significant difference was observed for the middle point P3 ($p = 0.127$).

For the Metha short stem the highest 3D micro motion were registered at the proximal medial part of the implant and were significantly higher compared to those of the CLS stem (P1: Metha 85.1 ± 23.1 vs. CLS 21.8 ± 5.6; $p < 0.0001$). In contrast the largest micromotions for the CLS were recorded at the distal tip of the stem (P5: Metha 15.3 ± 3.9 μm vs. CLS 105.6 ± 20.8 μm; $p < 0.0001$). Low 3D micro motion without a significant difference were registered for both implants in the median region (P3: Metha 18.2 ± 2.0 μm vs. CLS 27.2 ± 13.2 μm; $p = 0.127$).

Revision scenario (CLS and CLS-revision)

In the revision scenario, no significant differences in the 3D micro motion were observed between the primary CLS and CLS as a revision stem at the proximal points P1 ($p = 0.746$) and P2 ($p = 0.669$) and distal points P4 ($p = 0.459$) and 5 ($p = 0.063$) (Figs. 3 and 4). Only in the middle part at P3 the CLS-revision group revealed significant different 3D micro

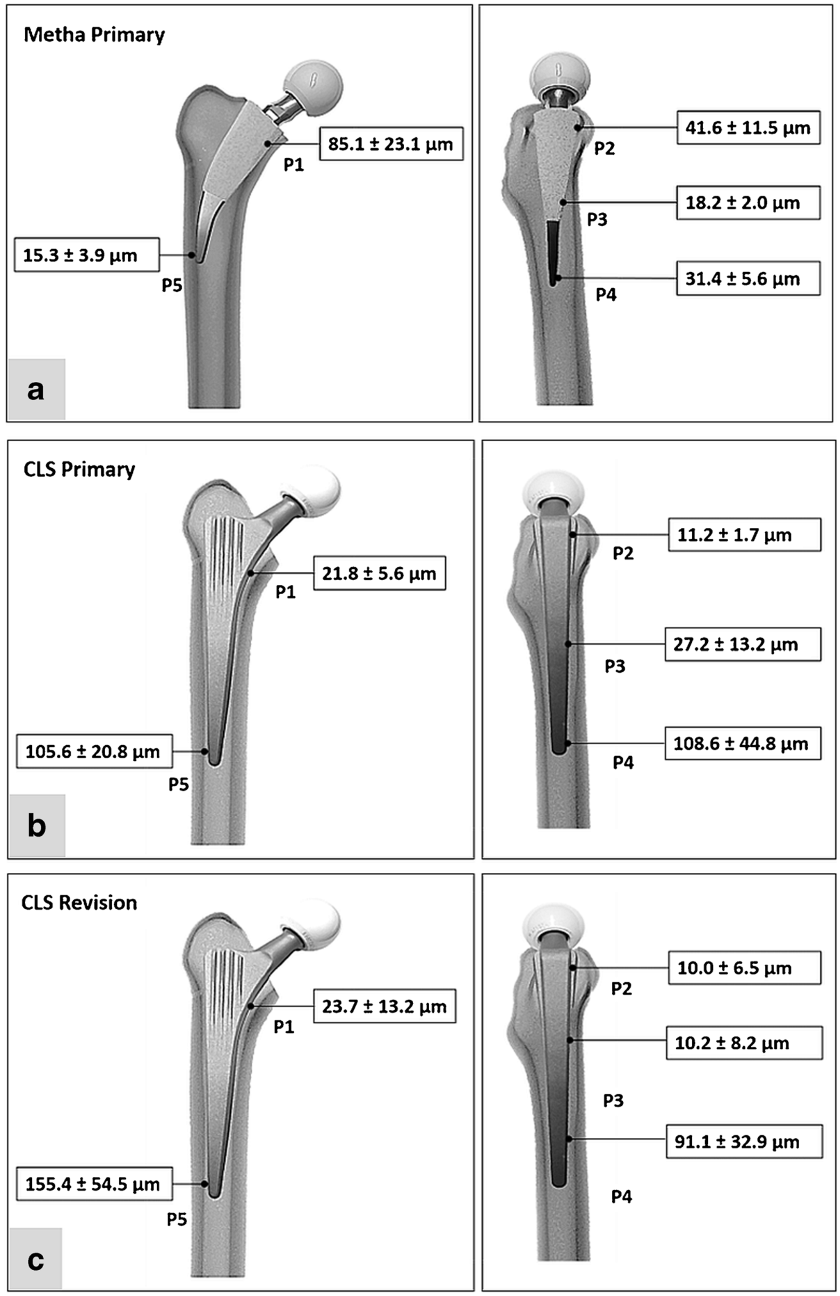

Fig. 3 3D-MM determined for **a**) the primary situation of the Metha short stem (Metha-primary), **b**) the primary situation of the CLS standard stem (CLS-primary), and **c**) the revision of the Metha short stem with a standard CLS stem (CLS-revision). Measurements were performed at 5 interface points: P1 = proximal medial, P2 = ventral proximal, P3 = ventral median, P4 = ventral distal, and P 5 = distal lateral

motion, which however were lower compared to the primary CLS scenario (P3: CLS 27.2 ± 13.2 μm vs. CLS-revision 10.2 ± 8.2 μm; $p = 0.022$).

When revising the Metha implant and implanting the standard CLS stem as the revision implant, a defect at the calcar region was observed in all specimens, which was not completely filled by the CLS stem (Fig. 5). However, comparing the 3D micro motion at this level (P1 and 2) did not reveal a difference between the primary CLS and CLS-revision situation (P1: CLS 21.8 ± 5.6 μm vs. CLS-revision 23.7 ± 13.2 μm ($p = 0.746$) and P 2: CLS 11.2 ± 1.7 μm vs. CLS-revision 10.0 ± 6.5 μm; $p = 0.669$).

Discussion

This study provides the biomechanical rational that a partially neck preserving and metaphyseal anchored SHA can safely be revised with a conventional THA stem if large bone defects are not present. The results demonstrate that the micromotions for the CLS stem used to revise the short stem are comparable to the same CLS stem in a primary situation. Besides, the obtained data indicate a stable revision situation which offers sufficient primary stability to allow good osseous integration.

Evaluation of the primary implantation situation of the Metha SHA and CLS THA demonstrated an adequate initial

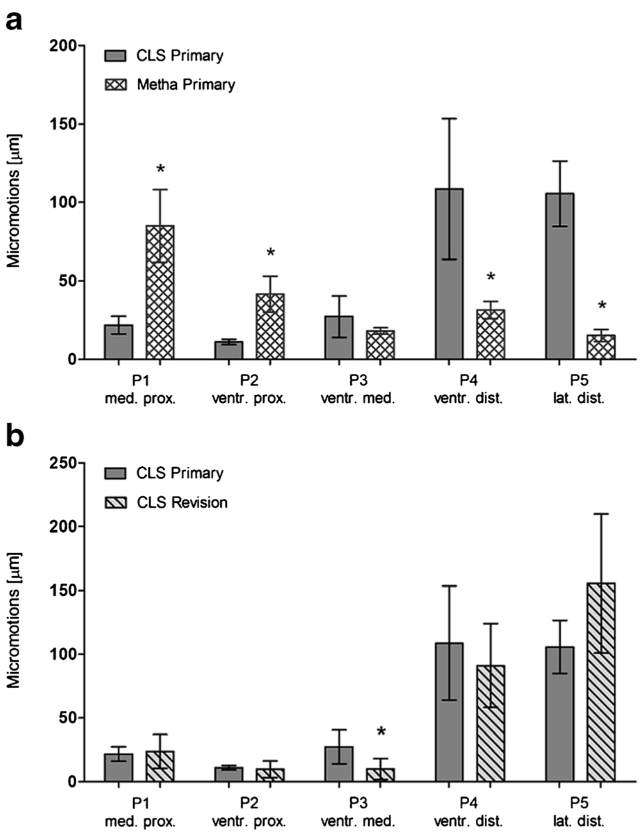

Fig. 4 Direct comparison of the 3D-MM for the 5 interface points. **a**) CLS-primary vs. Metha-primary stem. **b**) CLS-primary vs. CLS-revision stem. No significantly higher 3D–MM were registered for the CLS-revision stem after revising the Metha short stem. *Asterisk* (*) indicates significance to the CLS-primary ($p < 0.05$)

primary stability. The Metha stem revealed 3D micro motion remained under the critical threshold of 150 μm which is assumed to be the prerequisite for osseous integration [19]. Those results are in line with previous biomechanical data reporting favourable initial primary stability and strains [8, 20]. The available clinical medium-term data further support those biomechanical data. Schnurr et al. similarly evaluated 1888 Metha SHAs after a mean of six years and reported an aseptic loosening rate of 0.6% [1]. Von Lewinski et al. found in a series of 1953 Metha SHAs an aseptic loosening rate of 1.3% (26 cases) after three to ten years [5]. A review analysis reported a revision rate of 1.2% after a mean of 3.7 years including the initial breakage of the modular stem with a titanium adapter [3].

The good primary stability of the CLS THA found in this study goes along with the excellent long term survival rates of this stem which have been documented in multiple studies [12–14]. It further corresponds with the proximal load transfer concept of the stem. Notably, we also observed that in most CLS implants the 3D micro motion at the distal tip reached or exceeded the threshold of 150 μm meaning that an osseous integration is not expected. However, this is not a contradicting finding for the good initial stability of the CLS stem, but supports the design rational with a proximal anchorage and load transfer. The thin distal stem is not intended to "fit and fill" the medullary canal in order to avoid stress shielding [21], and also does not need osseous integration to result in a secondary stable stem [13]. This finding also explains the high variability of our data at the distal points and also between the CLS and CLS as a revision stem. These findings are in accordance with Nadorf et al. and Buhler et al., who similarly found the highest 3D micro motion at the distal tip of the CLS stem [22, 23].

Revising the Metha SHA implant with the CLS stem as a revision implant demonstrated, that no significant differences of 3D micro motion were found between revision and primary CLS settings at most of the tested points. Moreover, none of the revision points revealed significantly higher 3D micro motion compared to the primary CLS implantation. Also, the pattern resembled the primary implantation with the lowest 3D micro motion registered at the proximal and metaphyseal region and the highest observed in the distal proportion. This supports the assumption that in a revision situation after failure of SHA sufficient bone stock is conserved in

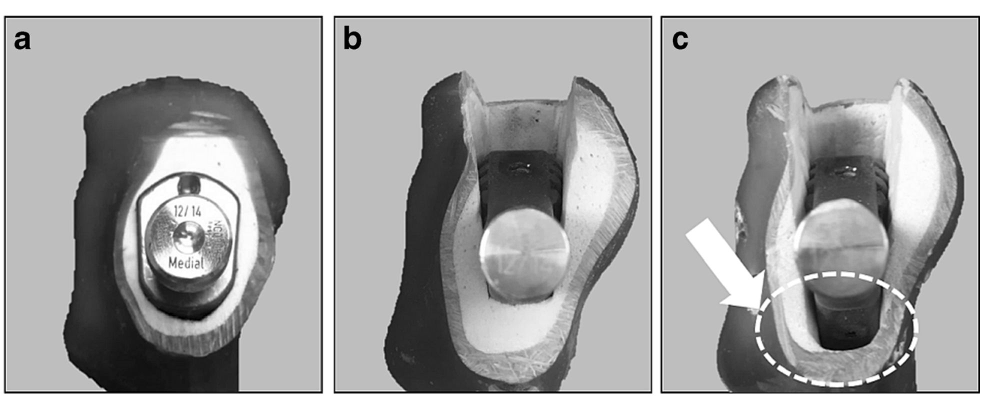

Fig. 5 Composite femurs after implantation of: **a**) the Metha short stem (Metha-primary), **b**) the primary CLS standard stem (CLS-primary), and **c**) the revision of a Metha short stem (**a**) with a CLS standard stem (**b**) (CLS-revision). In the revision scenario a defect remains at the calcar from the curved Metha short stem implant design (*white arrow* and *circle*)

the proximal, metaphyseal region to anchor a conventional CLS implant. However, it has to be noticed that this in vivo evaluation only accounts for situations without the presence of large and complicated defects of the bone stock or fractures.

Notably, the revision situation resulted in a bony defect at the calcar which was still visible after revision with the CLS stem (Fig. 5). This bony defect is related to the curved and wider design of the short stem, which aims for a proximal-medial support at the calcar region [5]. However, at the calcar level where the bone defect was located no significant difference was observed in the 3D micro motion (P1 and 2) between the primary and revision situation of the CLS stem. Therefore, it can be assumed that this defect at the calcar does not affect the initial stability, a fact which is probably related to the CLS design with the longitudinal ribs on the anterior and posterior surface at the proximal stem. Those ribs are not reached by the calcar defect and still allow in the revision situation to provide a large contact area with simultaneous rotational stability [12, 13]. Nevertheless, surgeons should be aware that larger defect situation, especially affecting the anterior and posterior surface might reduce the stability of the CLS stem. In such situations implants with a more distal anchorage or even a revision stem should be taken into account [18, 24].

Comparison of our biomechanical data with in vivo data is difficult, as to our knowledge clinical studies about the outcome of revision procedures after SHA are currently not available. One study with a series of 1953 Metha SHAs reported 38 SHA failures, from which 34 could be revised with cementless standard THA (90%), two with SHA (5%), and only two (5%) requiring a revision stem [5]. Although those data support our biomechanical in vitro findings, a longer clinical and radiological follow-up is necessary to draw a definite conclusion.

Besides, further investigations have to provide more evidence for which implant in a revision situation should be applied for the variety of defects that might occur. This appears even more important as multiple SHA with completely different anchorage patterns as well as femoral resection levels are available [3, 4]. Therefore, the current data can only apply to the implants evaluated and also cannot be used uncritically in the clinical setting as in vitro data have to be transferred into clinics cautiously.

Further limitations of this study have to be considered. First, the study was performed with composite sawbones, resulting in different absolute micromotions values compared to human bones which might simulate a better in vitro behaviour. However, composite bones allow minimizing the high degree of variability found in cadaveric bones and allow a more standardized way of comparing implants as desired in this study [23, 25]. Second, we only simulated a revision scenario with the absence of large bone defects. Larger bone defects, which might occur in periprosthetic fractures or during infection, are a different entity and have to be analyzed separately. Third, both stems are cementless implants which require bone ingrown, while this study only considered the initial fixation and did not evaluate the long-term biological fixation. Finally, biomechanical studies are in vitro studies and do not necessarily reflect the in vivo situation, therefore the results have to be reevaluated in a clinical setting.

In conclusion, the results of this study show that the metaphyseal anchored Metha SHA implant offers a good initial stability, which is clearly different from the conventional CLS THA stem. The data also indicate that in a revision scenario, the Metha short stem implant can safely be revised with a cementless CLS stem, reaching similar primary stability as a CLS stem during a primary implantation. However, it has to be noted that this only accounts for uncomplicated revision scenarios without larger bony defects and also has to be confirmed in a clinical setting.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent This article does not contain any studies with human participants wherefore no informed consent had to be obtained from individual participants.

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