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Influence of size and CCD-angle of a short stem hip arthroplasty on strain patterns of the proximal femur – an experimental study

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Purpose: The number of primary total hip arthroplasties (THA) is steadily increasing. Over the last decade numerous so-called short stem hip arthroplasties were introduced on the market. The aim of these implants with a predominantly metaphyseal anchorage is to reduce stress shielding and thereby the risk of aseptic loosening. One of the short stem arthroplasties with predominant metaphyseal fixation is the METHA® short stem (Aesculap, Tuttlingen, Germany). In order to reconstruct the biomechanics the METHA stem is available in different sizes with different centrum-collum-diaphysis-angles (CCD-angle). In this study, we want to address the research question of how the size of the implant and different CCD-angles influence the strain patterns of the proximal femur. *Methods*: Three different stem sizes (size 2, 3 and 4 – CCD-angle 130°) and three stems with different CCD-angles (size 3 – 120°, 130° and 135° CCD-angle) were successively implanted in a synthetic femur. Eight strain gauges monitored the corresponding strain patterns of the proximal femur. *Results*: Independent of stem size and CCD-angle only small changes in the strains were recorded around the distal part of the METHA stem when compared to the intact femur. However, all stems increased the strains in the region of the calcar. This was most pronounced by smaller CCD-angles and major sizes. *Conclusion*: The stem size and CCD-angle primarily influence the region of the calcar. Greater sizes and smaller CCD-angles lead to increased strains at the calcar. The other regions are hardly influenced by the stem size and CCD-angle of the femoral component.

Key words: *short stem arthroplasty, METHA stem, biomechanical testing, centrum-collum-diaphysis-angle, strain gauges, strain patterns*

1. Introduction

The implantation of a total hip arthroplasty (THA) represents the surgery of the century [19]. This is justified by excellent clinical outcome and longevity [19]. Due to the fact that the indication for THA has enlarged also to younger age and new designs like short stem arthroplasties were developed in order to allow more options for revision and to reduce possible stress-shielding due to more physiological force transmission [1], [2], [14], [16], [22], [23], [26], [27]. Over the last decade a high number of so called short stem arthroplasties has been introduced on the market. Thereby the percentage of implanted short stem arthroplasties increased. The more physiological strain patterns of a short stem THA are supposed to prolong the period until aseptic loosening occurs. For the METHA short stem (Aesculap, Tuttlingen, Germany) a predominant metaphyseal fixation was proven in biomechanical studies [8], [13]. In order to restore the biomechanical principle of the hip joint and the correct leg length, different options of the METHA short stem including alternatives of the Centrum-Centrum-Diaphysis-angle (CCD-angle) are necessary and available. By now, hardly any data exist presenting information of the influence of a THA with different CCD-angles on the strain patterns.

In addition, for these short stem arthroplasties the correct stem size seems to be very important. If the

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surgeon chooses the size too small, the risk of sintering and loosening due to greater micromotions is increased. If the surgeon chooses the size too big, the risks of a difference in limb length as well as an intraoperative fracture are increased.

Thus, this experimental study analysed the changes in strain patterns caused by both a variation of the CCD-angle (size 3 – 120°, 130° and 135°) and the size (size 2, 3 and 4 – 130°-CCD-angle) of the short stem arthroplasty METHA using strain gauges on a synthetic femur. These strain patterns were compared to the non-implanted situation.

2. Materials and methods

Strain gauges were used to measure strain patterns prior and after implantation of the METHA stem of different size and different CCD-angle. A synthetic femur was used in this setting as it was done in previous biomechanical studies in order to exclude different anatomy and quality of bone [5], [10], [11], [17]. The preparation and biomechanical testing was similar to the ones described previously [8], [13].

2.1. Preparation of the synthetic femur

A synthetic femur (4th generation left adult composite femur, Sawbones Europe, Malmö, Sweden) was used. The femur was embedded distally in a metal cylinder. The distance extending from the proximal potting to the notch of the femoral neck was 300 mm. A form fitted mould of the proximal femur within an adjustable frame, manufactured based on a previously used femur-aligned reference system [3], [4], guaranteed a standardized embedding procedure (sagittal and frontal plane at 0°) using methylmethacrylate (Technovit 4004; Heraeus Kulzer GmbH, Wehrheim, Germany) [8], [13].

2.2. Implants

The METHA stem (Fig. 1) is a cementless short stem, which is anchored directly within the closed bony ring of the femoral neck and metaphysis. To analyse the influence of the stem size on the strain patterns of the proximal femur METHA short stems of size 2, 3 and 4 with a CCD-angle of 130° were tested after determining size 3 as the correct size according to X-rays. In addition, size 3 METHA stems with CCD-angles of 120°, 130° and 135° were tested. Each stem was implanted according to the manufacturer's recommendation, while X-ray images were captured to verify correct implant positioning. For each stem a 32 mm-head (length S) was used.

Fig. 1. The METHA short stem arthroplasty in anterior and lateral view

2.3. Strain measurement

Strain measurements represent deformations of the strain gauges, and thus, of the synthetic bone under loading. Eight strain gauges (3/350 RY91; Hottinger Baldwin Messtechnik GmbH (HBM), Darmstadt, Germany) were bonded to the medial and lateral aspects of the femur at four levels (A-D): 45 (30 mm for the lateral strain gauge), 70, 90, and 150 mm distal to the notch of the femoral neck (Fig. 2). Each strain gauge at level A-D should illustrate the changes in strain in one of the Gruen zones to enable a comparison of strain measurement and DXA scans.

The strain gauges at level D were located approximately 50 mm from the distal end of the implant, far enough so that their measurements should not be affected by the implant presence. Thus, the strain gauge readings were able to identify if identical loading conditions were applied to the intact and implanted femur [3], [4].

Before mounting the strain gauges, the bone surface was smoothed with fine sandpaper (#280) and carefully cleaned and degreased with ethanol followed by a cleanser (RMS1, HBM, Darmstadt, Germany

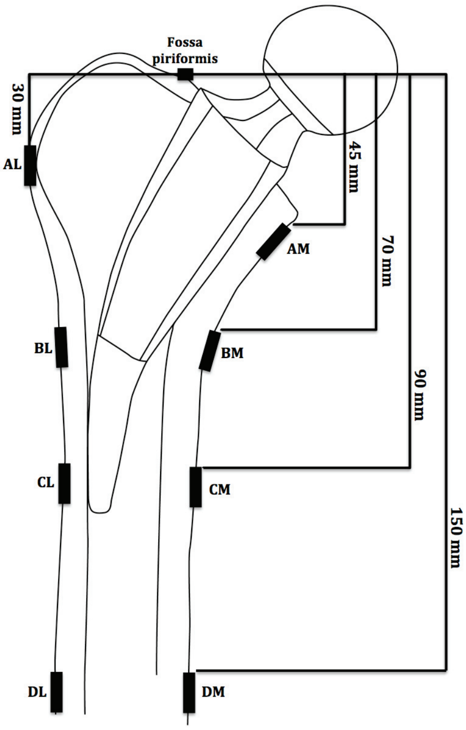

Fig. 2. Illustration of positions of the strain gauges on the femur with an implanted METHA short stem

(HBM)). An optical tracking system based on infrared-marker tracking (Polaris P4, Northern Digital Inc., Waterloo, Ontario, Canada) was used to ensure perpendicular alignment to the longitudinal axis of the femur as well as the precise positioning of the strain gauges on the femur. Finally, the strain gauges were bonded with a two-component polymethylmethacrylate adhesive (X60, HBM) and covered with a polyurethane protective (PU 120, HBM). The leads of the gauges were soldered to the wires and connected with a CANHEAD base module (CB1014, HBM) including an amplifier module (CA1030, HBM). The catmanEASY software (Version 3.1, HBM) recorded the data. To avoid heating of the gauges, a bridge excitation voltage of 0.5 Volts was selected. Data was attained at a frequency of 100 Hz, with a low-pass cutoff frequency of 10 Hz.

2.4. Mechanical application and measurement protocol

The femur was placed on a 15 kN load cell of a materials testing system (MTS Mini Bionix 858; MTS Systems Corporation, Eden Prairie, Minnesota, USA) using a custom-made jig, consisting of an aluminium cylinder and a platform the angular position of which was steplessly adjustable. Using the rotating platform, a loading configuration was chosen that simulated a single-leg stance (8° adduction, 0° flexion) [3], [4]. For vertical loading, a floating bearing was attached to the MTS to avoid undesired horizontal forces and moments (Fig. 3). After zeroing the load cell and strain gauges the femur was loaded in a ramp profile up to an axial force of 800 N at a rate of 10 N/s. Using load control, the axial force of 800 N was kept constant for 90 seconds to reduce the influence of the creep effect. After 30 seconds, strains were recorded for the following 60 seconds and the average of these data was taken as the result for this run. The measurement procedure was repeated five times. For elastic recovery of the femur, there was an interval of eight minutes between each repetition. In order to verify the material linearity, a further measurement was performed where strains were recorded at 100 N loading increments to a maximum load of 800 N. At each level, the load was held for 10 seconds and strains were measured for 30 seconds. This procedure was first conducted on the non-implanted femur. Subsequently, the first METHA prosthesis (size 2, CCD-angle 130°) was implanted in the synthetic femur and the measurement protocol was repeated. Thereafter, the prosthesis was explanted and the prosthesis next in size was implanted. This procedure was repeated till all prostheses were tested. In addition, the METHA stems size 3 – 120°, 130° and 135° CCD-angles were tested.

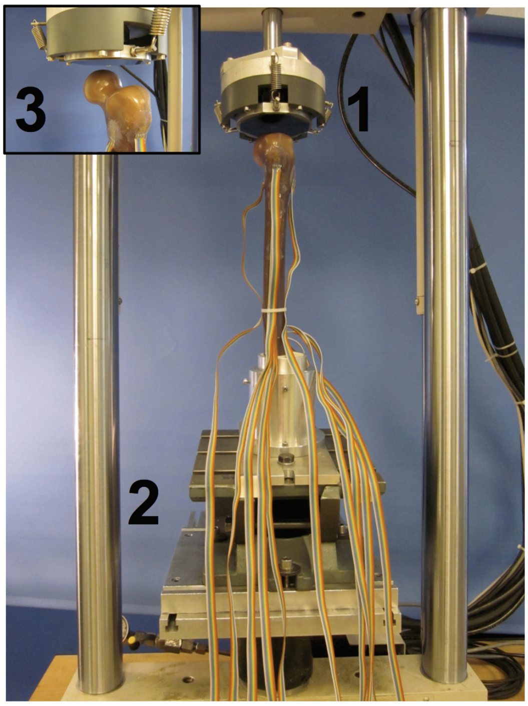

Fig. 3. Experimental setup of the biomechanical testing within the Material Testing System including the floating bearing, which eliminates horizontal forces (1 and 3), and a platform that allows positioning of the femur to simulate single-leg stance (2)

2.5. Analysis of data

The mean values of the two principal strains and the angles of the major principal strains during the five load repetitions without and with the implanted stems were determined. The difference between the principal strains reflected the strain of the bone surface at the corresponding strain gauge position. This value was calculated for each repetition and afterwards used for the further analysis. That was the result of a re-evaluation of the correct interpretation of strain gauge measurements and differs slightly from previous publications, where we analysed only the major principal strains [8], [13].

The results from the implanted femur were expressed as a percentage of the strains in the non-implanted femur. A statistical analysis with determination of significant differences was impossible because only one synthetic femur was used.

For determination of measurement repeatability the coefficient of variance (CV) of the five repetitions was computed for the difference between the principal strains. Strain readings from the load application where strains were recorded in 100 N increments were assessed for linearity between force and strain using a coefficient of linear regression R^2.

3. Results

3.1. Quality of strain measurement

The CV of the differences between the main principal strains within the five repetitions was always less than 0.6% (average 0.28%). Thus, measurement repeatability was excellent. The relationship between applied load and experimental strain was highly linear, with R^2 greater than 0.995 for all strain gauges on the femur in the intact and implanted conditions. This additionally proved the high quality of strain gauge bonding. After implantation of the stems, strain in the most distal gauges (level D) was always within a difference of 20% of the strain value in the non-implanted condition, demonstrating consistent loading conditions [3], [4].

3.2. Strain patterns in the intact femur

The strain values varied between the locations in the non-implanted femur (Fig. 4). As expected, negative strains were larger on the medial aspect (i.e., compressive loading), whereas positive strains were larger on the lateral aspect (i.e., tensile loading). The direction of the major principal strains was within a few degrees from the axis of the femur on the lateral aspect and nearly perpendicular to this axis on the medial aspect, correlating to tensile or compressive loading. Independent of tensile or compressive loading, the differences between the two principal strains are presented in the corresponding figures (as this represents the strain of the corresponding bone surface) (Figs. 4–6).

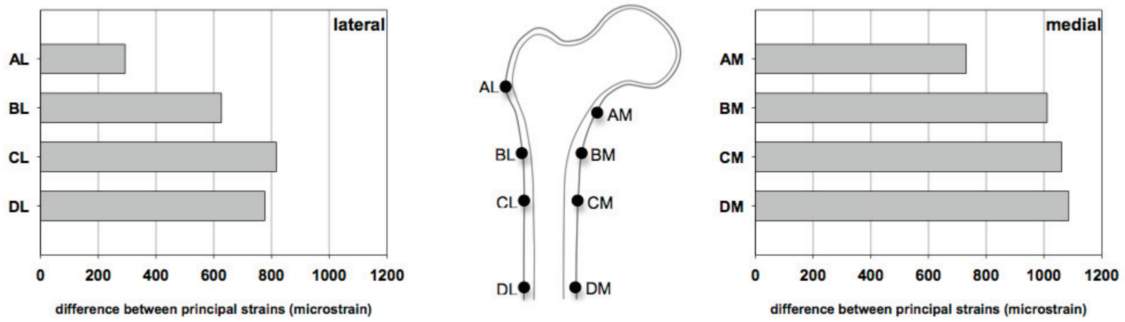

Fig. 4. Mean principal strains in the non-implanted femora at the different positions

3.3. Strain patterns after insertion of stems

Implantation of the METHA stem in different sizes and with different CCD-angles led to only small changes in the strains when compared with the intact femur at level B and C. Greater differences were recorded at level A in terms of strain increases at strain gauge AM and strain decreases at strain gauge AL (Figs. 5 and 6).

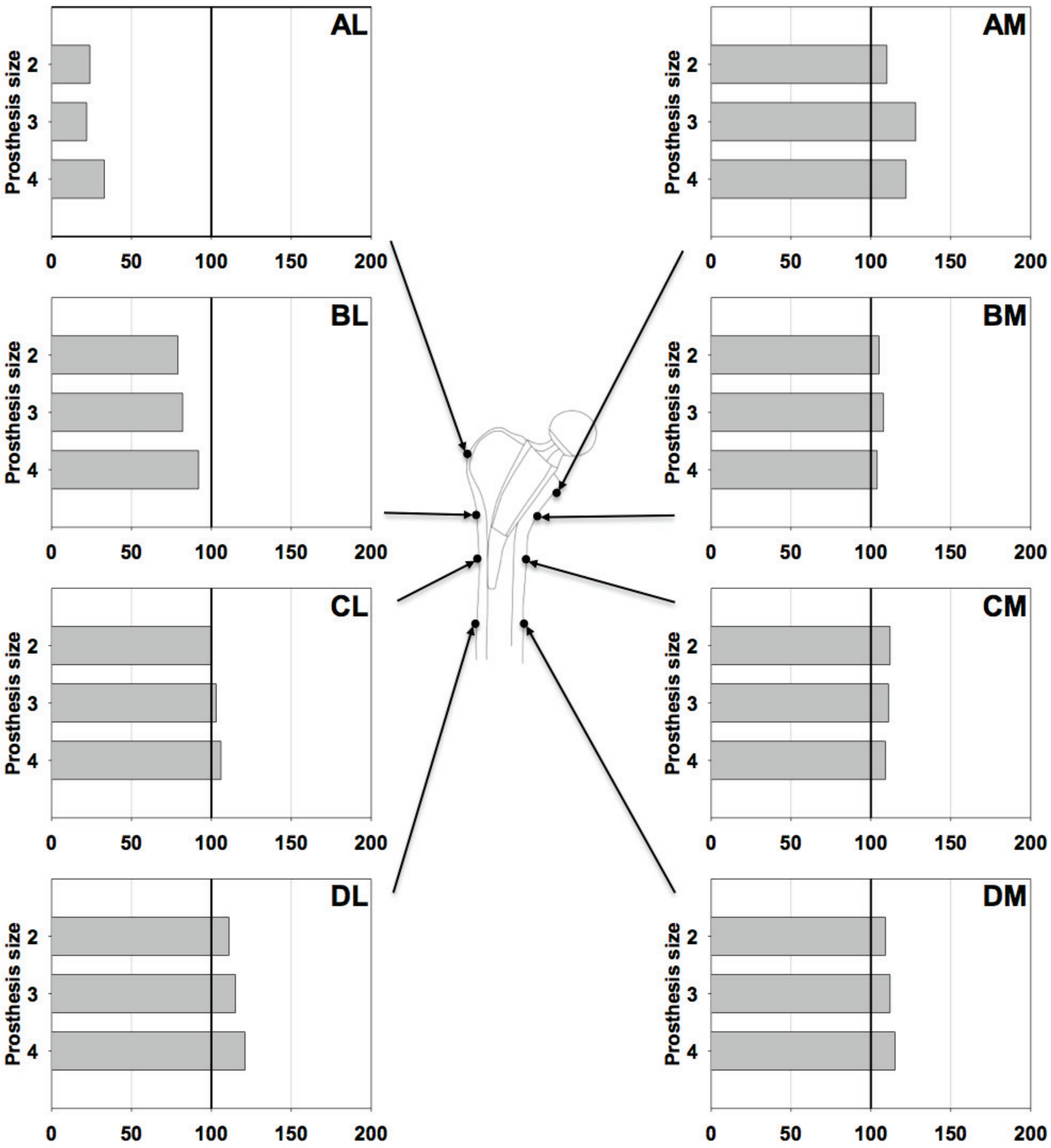

Fig. 5. Changes in mean principal strains after implantation of the METHA short stem of size 2, 3 or 4
(in % of the principal strain values in the non-implanted femora).
100% denotes the strain values in the non-implanted femora

Stem sizes

At levels B and C the strain after implantation of the different stem sizes only differed from the non-implanted condition by between –21% and +12% for size 2, between –18% and +11% for size 3 and between –8% and +9% for size 4 (Fig. 5). In the region of the greater trochanter, represented by strain gauge AL, there were decreases in strain by 76%, 78% and 67% for size 2, 3 and 4, respectively. Strains at measurement location AM (medial Gruen zone 7) were increased by 10% (size 2), 28% (size 3) and 22% (size 4).

CCD-angles

Results from the different CCD-angles revealed strains compared to the non-implanted between –12% and +8% (120°), –18% and +11% (130°) and –17% and +1% (135°) at level B and C (Fig. 6). In the region of the greater trochanter (strain gauge AL) the

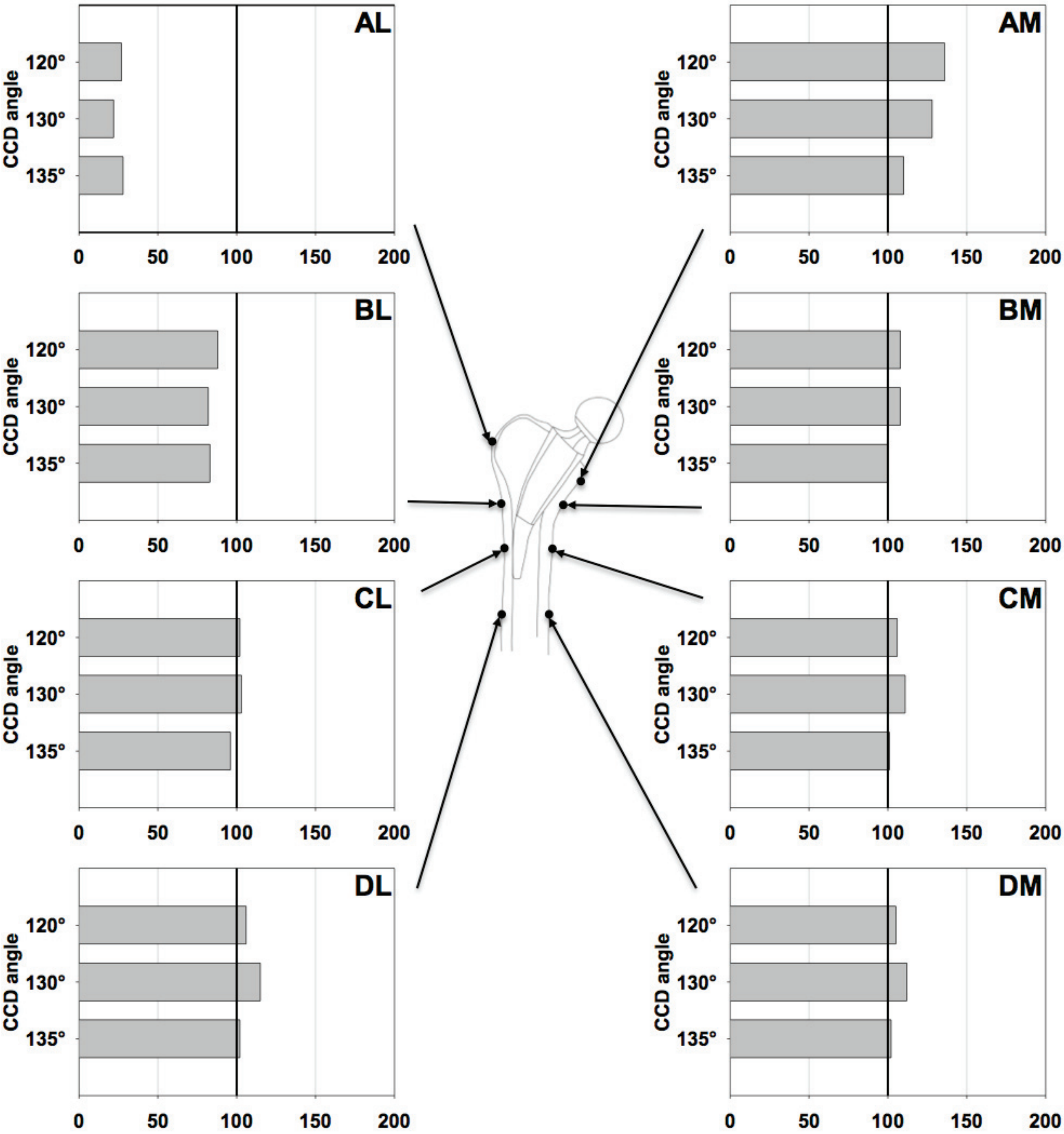

Fig. 6. Changes in mean principal strains after implantation of the METHA short stem of different CCD-variations (120°, 130° and 135°) (in % of the principal strain values in the non-implanted femora). 100% denotes the strain values in the non-implanted femora

strains decreased by 73% (120°), 78% (130°) and 72% (135°). Strains at measurement location AM were increased by 36% (120°), 28% (130°) and 10% (135°).

4. Discussion

By now a direct correlation between stress-shielding and clinical outcome after THA is not proven. However, it is consistent that the resorption of proximal femoral bone stock is associated with negative effects on the stability and survival of femoral implants [6], [20], [24]. Thus, the aim of this study was to determine the strain patterns in a proximal femur after implantation of a short stem with supposed primary metaphyseal anchorage. It was of particular interest to investigate the effect on strain patterns of the proximal femur due to divergences in size of the femoral implant and the variation of the CCD-angle.

The biomechanical data revealed for the two greater stem sizes as well as for a METHA with a CCD-angle of 120° and 130° considerably increased strains in the region of the calcar compared to that of a non-implanted synthetic femur. Relatively independent of stem size and CCD-angle the only location where a substantial decrease in strain was observed was around the greater trochanter. The other regions and level around the stem reveal hardly any divergence due to different stem sizes or different CCD-angles.

Because the strain patterns matched well to that of the non-implanted model, the problem of stress shielding seems to be negligible after implantation of the METHA stem. Clinically, it can be inferred that the size and the CCD-angle of the METHA short stem primarily influence the region of the calcar. Thus, varus anatomy of the proximal femur should be judged carefully when implanting a METHA with a CCD-angle of 120° and long heads.

Enoksen et al. investigated the deformation pattern and load transfer of an uncemented femoral stem coupled to different modular necks in human cadaver femurs [7]. The stems were tested with four different modular necks; long, short, retro and varus. The deformation of bone during loading was measured by strain gauge rosettes at three levels of the proximal femur on the medial, lateral and anterior side. The small differences of strain between the modular necks tested in this study are not expected to influence bone remodeling in the proximal femur. Furthermore, Goshulak et al. compared short-stem vs. standard length stemmed implants for stress shielding effects due to anteversion-retroversion, anterior-posterior position, and modular neck offset [12]. Three modular neck options were tested in the short-stem implants. Strain gauge values were collected to validate a Finite Element (FE) model, which was used to simulate the full range of physiologically possible anteversion and anterior-posterior combinations ($n = 25$ combinations per implant). No implant anteversion showed significant reduction in stress shielding ($\alpha = 0.05$, $p > 0.05$). In addition stress shielding was significantly higher in the standard-stem implant (63% change from intact femur, $p < 0.001$) than in short-stem implants (29–39% change, $p < 0.001$). The authors concluded that short-stem implants reduce stress shielding compared to standard length stemmed implants, while implant anteversion and anterior-posterior position had no effect. Furthermore, they believe that short-stem implants have a greater likelihood of maintaining calcar bone strength in the long term.

To date only one imaging and one biomechanical study exists analysing the influence of the resection height for the METHA stem on the offset and CCD-angle [8], [21]. Both studies revealed that the final position of the METHA stem and the CCD-angle were significantly higher with a lower neck resection (0 mm) and the offset was lower in this position compared to more proximal resections [21]. The biomechanical study provided further information about strain patterns [8]. The study revealed that the deeper the resection for implantation of the METHA stem, the more similar the strain patterns when compared to a non-implanted synthetic bone. Changes in strain patterns are induced by variation in the varus/valgus positioning of the implant resulting in different offsets. Special biomechanical or imaging studies analyzing the influence of the stem size or the CCD-angle of an implant on the strain patterns of the proximal femur do not exist.

In the meanwhile a number of studies reported mid-term results of the METHA® short stem [9], [18], [23], [25], [27]. Thorey et al. reported the outcome of 151 modular Metha short hip stem implants in 148 patients between March 2005 and October 2007 [23]. After a mean follow-up of 5.8 years the mean HHS increased from 46 ± 17 pre-operatively to 90 ± 5. The HOOS improved from 55 ± 16 pre-operatively to 89 ± 10 at the final follow-up. The Kaplan–Meier-survival rate was about 98% at the time of follow-up. In this study, the METHA stem with a CCD-angle of 130° and 135° was used. They concluded that the clinical and radiographic data of their study supported the principle of using short stems with metaphyseal anchorage. Lacko et al. compared 30 patients with implanted METHA short stems and 30 patients with implanted conventional Bicontact® stems [18]. In the METHA group, the mean pre- and post-operative Harris hip scores were 41.7 ± 9.9 (28–57) and 94.4 ± 5.1 (82–100), respectively. In the Bicontact group the values were 41.5 ± 11.9 (32–64) and 89.3 ± 11.2 (57–100), respectively. Within the group of implanted METHA only one subsidence of the METHA occurred. The authors concluded that the METHA short stem can be recommended as an optimal choice for use in younger patients with good bone quality who are expected to require THA re-implantation. Wittenberg et al. presented clinical and radiological data of 250 patients with implanted METHA stem [27]. At the mean follow-up of 4.9 years 85% of the patients were very satisfied with the results of the treatment, 14% were satisfied and 1% was dissatisfied. At that follow-up the average Harris Hip Score was 97 points. They revealed a five year Kaplan–Meier survival rate of 96.7%. The authors summarized that the mid-term clinical results with periprosthetic bone remodeling and without radiological signs of loosening confirm this metaphyseal short-stem treatment and fixation concept. Von Lewinski and Floerkemeier reported of their 10-year experience with the METHA short stem THA [25]. Retrospective after experience of a total of 1953 METHA stems they concluded that the implant is a bone-preserving option for various indications in selected patient groups including dysplastic hips. Of the 1953 METHA short stem THA 38 required a revision due to mechanical complication (1.9%). They revealed also that the METHA stem is an encouraging option in adults with the underlying diagnosis of osteonecrosis of the femoral head [9]. Analyzing 73 hips in 64 patients revealed an increase in Harris Hip Score from 41.4 to 90.6 points after a 34 months follow-up. The revisions performed (4.1%) were not specific for the short stem implant.

The results of a DXA analysis by Lerch et al. are apposite to the present study [20]. They proved a concentrated load distribution on the medial portion of the femur after implantation of the METHA stem. In the region of the calcar, bone mineral density exceeded the baseline value by 6.1% two years after implantation. Thus, both studies suggest a primary metaphyseal anchorage of the METHA stem.

Prior to this study we were aware that a synthetic femur cannot perfectly replicate in vivo conditions. However, a strong resemblance in mechanical properties to native bone with interspecimen variability of only between 2.6 and 3.1% for the axial and bending load was proven in previous studies [15]. A fairly high number of biomechanical studies previously also used synthetic femora. To avoid bone damage the applied axial load was limited to 800 N. However, as the linearity between force and strain was proven, the strain patterns do not depend on the absolute amount of the applied load, because the results of the implanted femur were expressed as a percentage of the strains in the non-implanted femur. Muscles and forces provided by other soft tissue were not simulated during biomechanical testing. However, it has been reported [4] that studies, in which the testing set-up did not feature muscles, can reliably analyse the strain patterns of the proximal femur [3], [4]. Furthermore, the effect of different lever arms could not be excluded due to different offsets of the stems with different CCD-angles. However, the aim of this study was to compare the strain patterns after implantation of the stems without bothering about the offset as in clinical practice the surgeon has to decide which type of stem is appropriate for the patient's anatomy.

5. Conclusions

As a conclusion, this study revealed similar strain patterns for the cementless METHA short stem arthroplasty with three different sizes and variations of the METHA with different CCD-angles. A greater size and a METHA with a CCD-angle of 120° and 130° revealed an increase in strain at the region of the calcar compared to the other METHAs tested. For clinical practice the data of the current study showed that the different variations of the METHA in CCD-angle and different sizes have only slight influence on the strain patterns.

Acknowledgements

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Conflict of interest

Three of the authors (Floerkemeier T, Windhagen H and von Lewinski G) are paid instructors for the company B.Braun Aesculap, Tuttlingen.

References

[1] BANERJEE S., PIVEC R., ISSA K., HARWIN S.F., MONT M.A., KHANUJA H.S., *Outcomes of short stems in total hip arthroplasty*, Orthopedics, 2013, 36(9), 700–707.

[2] BRAUN A., SABAH A., *Two-year results of a modular short hip stem prosthesis – a prospective study*, Z. Orthop. Unfall, 2009, 147(6), 700–706.

[3] CRISTOFOLINI L., JUSZCZYK M., TADDEI F., FIELD R.E., RUSHTON N., VICECONTI M., *Stress shielding and stress concentration of contemporary epiphyseal hip prostheses*, Proc. Inst. Mech. Eng. H, 2009, 223(1), 27–44.

[4] CRISTOFOLINI L., JUSZCZYK M., TADDEI F., VICECONTI M., *Strain distribution in the proximal human femoral metaphysis*, Proc. Inst. Mech. Eng. H, 2009, 223(3), 273–288.

[5] DAVIS E.T., OLSEN M., ZDERO R., PAPINI M., WADDELL J.P., SCHEMITSCH E.H., *A biomechanical and finite element analysis of femoral neck notching during hip resurfacing*, J. Biomech. Eng., 2009, 131(4), 041002.

[6] DECKING R., PUHL W., SIMON U., CLAES L.E., *Changes in strain distribution of loaded proximal femora caused by different types of cementless femoral stems*, Clin. Biomech., Avon, Bristol 2006, 21(5), 495–501.

[7] ENOKSEN C.H., GJERDET N.R., KLAKSVIK J., ARTHURSSON A.J., SCHNELL-HUSBY O., WIK T.S., *Deformation pattern and load transfer of an uncemented femoral stem with modular necks. An experimental study in human cadaver femurs*, Clin. Biomech., Avon, Bristol 2016, 32, 28–33.

[8] Floerkemeier T., Gronewold J., Berner S., Olender G., Hurschler C., Windhagen H., von Lewinski G., *The influence of resection height on proximal femoral strain patterns after Metha short stem hip arthroplasty: an experimental study on composite femora*, Int. Orthop., 2013, 37(3), 369–377.

[9] Floerkemeier T., Tscheuschner N., Calliess T., Ezechieli M., Floerkemeier S., Budde S., Windhagen H., von Lewinski G., *Cementless short stem hip arthroplasty METHA®) as an encouraging option in adults with osteonecrosis of the femoral head*, Arch. Orthop. Trauma Surg., 2012, 132(8), 1125–1131.

[10] Fottner A., Schmid M., Birkenmaier C., Mazoochian F., Plitz W., Volkmar J., *Biomechanical evaluation of two types of short-stemmed hip prostheses compared to the trust plate prosthesis by three-dimensional measurement of micromotions*, Clin. Biomech., Avon, Bristol 2009, 24(5), 429–434.

[11] Görtz W., Nagerl U.V., Nagerl H., Thomsen M., *Spatial micromovements of uncemented femoral components after torsional loads*, J. Biomech. Eng., 2002, 124(6), 706–713.

[12] Goshulak P., Samiezadeh S., Aziz M.S., Bougherara H., Zdero R., Schemitsch E.H., *The biomechanical effect of anteversion and modular neck offset on stress shielding for short-stem versus conventional long-stem hip implants*, Med. Eng. Phys., 2016. DOI: 10.1016.

[13] Gronewold J., Berner S., Olender G., Hurschler C., Windhagen H., von Lewinski G, Floerkemeier T., *Changes in strain pattern after implantation of a short stem with metaphyseal anchorage compared to a standard stem: an experimental study in synthetic bone*, Orthop. Rev. Pavia, 2014, 6, 5211, 25–32.

[14] Gulow J., Scholz R., F. von Salis-Soglio, *Short-stemmed endoprostheses in total hip arthroplasty*, Orthopade, 2007, 36(4), 353–359.

[15] Heiner A.D., Brown T.D., *Structural properties of a new design of composite replicate femurs and tibias*, J. Biomech., 2001, 34(6), 773–781.

[16] Hutt J., Harb Z., Gill I., Kashif F., Miller J., Dodd M., *Ten year results of the collum femoris preserving total hip replacement: a prospective cohort study of seventy five patients*, Int. Orthop., 2013, 38(5), 917–22.

[17] Khanna G., Bourgeault C.A., Kyle R.F., *Biomechanical comparison of extended trochanteric osteotomy and slot osteotomy for femoral component revision in total hip arthroplasty*, Clin. Biomech., Avon, Bristol 2007, 22(5), 599–602.

[18] Lacko M., Filip V., Cellar R., Vasko G., *Our experience with the metha short hip stem*, Acta Chir. Orthop. Traumatol. Cech., 2014, 81(1), 70–76.

[19] Learmonth I.D., Young C., Rorabeck C., *The operation of the century: total hip replacement*, Lancet, 2007, 370(9597), 1508–1519.

[20] Lerch M., von der Haar-Tran A., Windhagen H., Behrens B.A., Wefstaedt P., Stukenborg-Colsman C.M., *Bone remodelling around the Metha short stem in total hip arthroplasty: a prospective dual-energy X-ray absorptiometry study*, Int. Orthop., 2011, 36(3), 533–538.

[21] Mihalko W.M., Saleh K.J., Heller M.O., Mollard B., Konig C., Kammerzell S., *Femoral neck cut level affects positioning of modular short-stem implant*, Orthopedics, 2009, 32(10 Suppl), 18–21.

[22] Patel R.M., Stulberg S.D., *The rationale for short uncemented stems in total hip arthroplasty*, Orthop. Clin. North Am., 2014, 45(1), 19–31.

[23] Thorey F., Hoefer C., bdi-Tabari N., Lerch M., Budde S., Windhagen H., *Clinical results of the metha short hip stem: a perspective for younger patients?*, Orthop. Rev., (Pavia), 2013, 5(4), e34.

[24] Umeda N., Saito M., Sugano N., Ohzono K., Nishii T., Sakai T., Yoshikawa H., Ikeda D., Murakami A., *Correlation between femoral neck version and strain on the femur after insertion of femoral prosthesis*, J. Orthop. Sci., 2003, 8(3), 381–386.

[25] Von Lewinski G., Floerkemeier T., *10-year experience with short stem total hip arthroplasty*, Orthopedics, 2015, 38(3 Suppl), S51–S56.

[26] Von Schulze Pellengahr C., Fottner A., Utzschneider S., Schmitt-Sody M., Teske W., Lichtinger T., Esenwein S.A., *Uncemented arthroplasty of the hip*, Orthopade, 2009, 38(5), 461–470.

[27] Wittenberg R.H., Steffen R., Windhagen H., Bucking P., Wilcke A., *Five-year results of a cementless short-hip-stem prosthesis*, Orthop. Rev., Pavia, 2013, 5(1), e4.