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ORIGINAL STUDY

Influence of varus/valgus positioning of the Nanos® and Metha® short-stemmed prostheses on stress shielding of metaphyseal bone

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The aim of this study was to analyze bone remodeling around the Nanos® (Smith & Nephew) and Metha® (Aesculap AG) implants as a function of varus/valgus stem positioning. In 75 patients with diagnosed coxarthrosis, either Nanos® (n= 51) or Metha® (n= 24) prostheses were implanted. Digital assessment of plain radiographs immediately, 97 days, and 381 days after THA showed no clinically-relevant migration, angulation, or change in offset and center of rotation. The DEXA scans showed significant BMD changes in Gruen zones 1 (-12.8%), 2 (-3.3%), 6 (+6.4%), and 7(-7.8%)(t-test). The pre/postoperative CCD for the Nanos® was 129°/ 135° and for the Metha® 131°/ 127°. Linear regression analysis showed no prediction for BMD by postoperative CCD or stem type.

In conclusion, there was no clinically-relevant influence on proximal femur BMD according to varus/valgus implantation of the Nanos® or Metha® prostheses.

Keywords : DEXA ; nanos ; metha ; bone remodeling ; tha ; varus/valgus alignment ; stress-shielding.

INTRODUCTION

Studies investigating strain distribution within the proximal femur after the implantation of short-stemmed prostheses have reported conflicting results regarding their ability to achieve proximal load transfer *(14,23,24,24)*.

Selective proximal load transfer is considered one important advantage of short compared to conventional stems, which typically produce clinically-relevant stress shielding *(25)*. This is important because there is evidence that bone loss around femoral stems might be associated with an increased risk of aseptic loosening *(13)*.

In addition, the preservation of metaphyseal bone when using short-stemmed prostheses should facilitate the exchange to conventional prostheses, for instance, in cases of aseptic loosening *(16)*. However, evidence, especially regarding improved options for revision THA, is still pending.

Investigations of load transfer after femoral stem insertion have been generally performed using DEXA measurements *(1,2,5,9,23,29)*, although other study groups have favored CT-scans *(22)*.

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The Nanos® prosthesis (Smith & Nephew GmbH, Marl, Germany) (Figure 1B) is designed to affix in the calcar region to ensure optimal load transfer, and to gain support along the distal lateral cortex to compensate for varus loading. The proximal titanium plasma surface roughness both increases surface area and ensures superior primary stability. The addition of calcium phosphate (BONIT®) accelerates the osseointegration process (courtesy of Smith & Nephew GmbH, Marl, Germany).

Very good short and medium-term clinical results have been reported for the Nanos® prosthesis, with postoperative HHS improvements to 96.5 after 1.2 years (Goetze 2010, n = 36) and 97.6 after 5.2 years (Ettinger 2011, n = 72) *(8,15)*.

The Metha® non-cemented stem (Aesculap AG, Tuttlingen, Germany) (Figure 1A) is anchored in the metaphysis within the closed ring of the femoral neck. The conical shape promotes primary stability and proximal force transfer. The Plasmapore®µ-CaP coating of the entire proximal surface encourages rapid secondary osseointegration (courtesy of Aesculap AG, Tuttlingen, Germany).

A clinical study of the Metha® prosthesis with a follow-up of 5.8 years showed an HSS improvement from 46 to 90, although three stems required revision due to subsidence *(31)*. In a five-year analysis of 250 Metha® stems, an HHS improvement to 97 was observed. The five-year Kaplan-Meier survival rate was 96.7%, even without accounting for material-related adapter failures *(34)*. These failures occurred due to fatigue of the original titanium alloy modular neck adapters, and were eliminated by the manufacturer, who replaced them with cobalt-chromium adapters *(10)*.

For the Metha® and Nanos® prostheses, variations in varus/valgus implant positioning induce changes in strain patterns *(11,21,28)*. Because

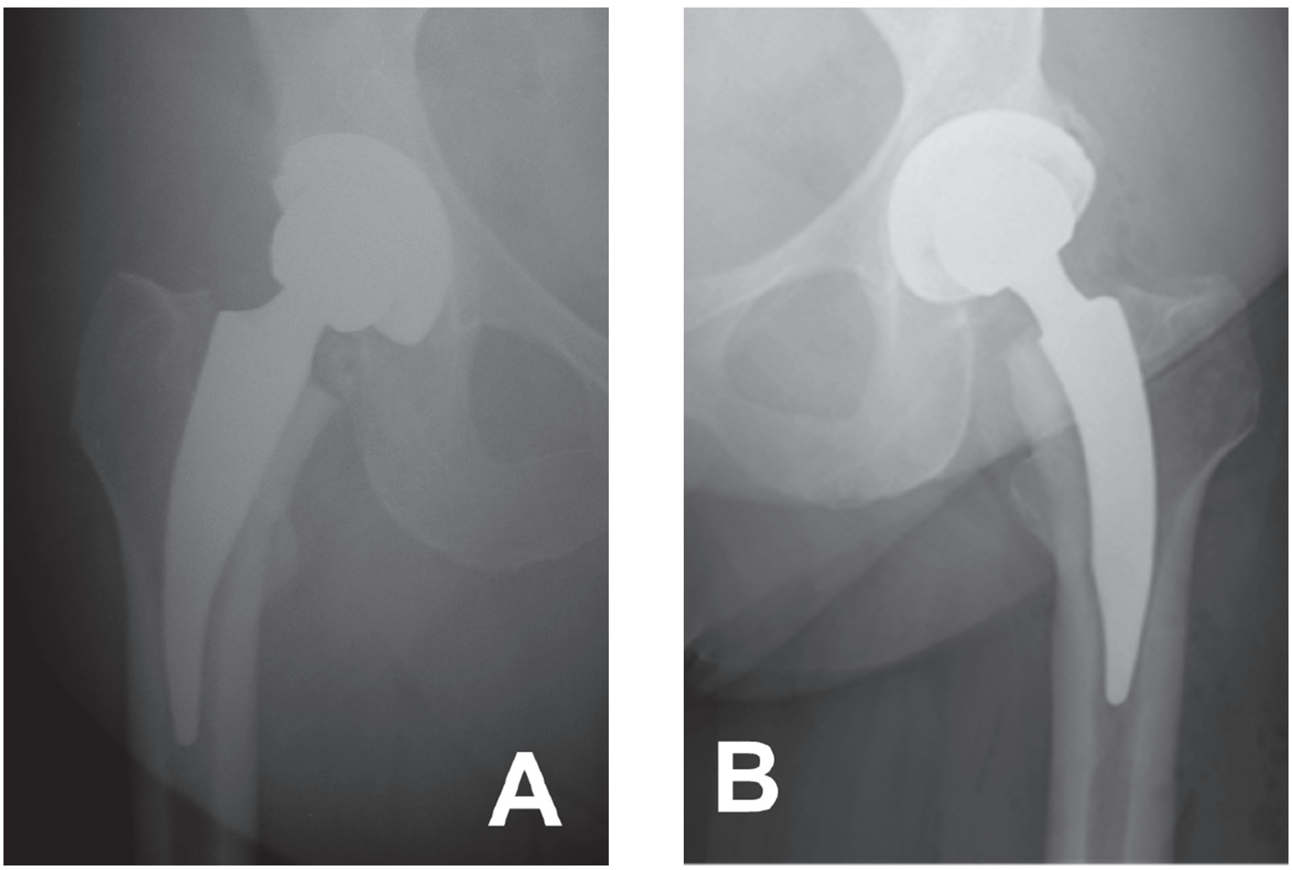

Fig. 1. — Metha® prosthesis (A), Nanos® prosthesis (B)

of the similar concepts of force transmission, the study results of Florkemeier et al. (2013) and Speirs et al. (2007) can most likely be applied also to other "calcar-guided" stems, and in particular, to stems that are designed to load the calcar as well as the lateral cortex *(10,11,19,28)*.

These study results are particularly important because the Nanos® stem concept includes offset variation by implantation with different CCD (caput collum diaphyseal) angles (Smith & Nephew GmbH, Marl, Germany). Furthermore, implantation of short-stemmed implants used preferentially with a minimally-invasive approach can result in suboptimal prosthesis placement *(28)*.

It has also been suggested that the indications for the use of short-stemmed implants be widened to include coxa vara and valga to take advantage of potential benefits, particularly for younger patients. It has been discussed whether suboptimal placement of short-stemmed implants in terms of varus/valgus alignment could be tolerated within certain limits in such anatomic situations *(11)*.

On the other hand, one must consider that the majority of studies on force transmission by short-stemmed implants do not report biomechanical data like the position of center of rotation (COR), offset (OFF) or varus/valgus positioning *(1,6,15,24,24)*. Thus, conclusions regarding the medium and long-term effects of varying placement of short-stemmed implants on stress shielding and long-term implant survival are difficult to draw.

In addition, the defined ranges of CCD interpreted as varus, neutral, or valgus differ for short-stemmed designs *(3,20,21)*.

These circumstances must be considered as important limitations regarding both the interpretation and comparability of study results for short-stemmed prostheses.

Both stems are classified as "partial collum with neck preserving osteotomy" following an analysis and categorization of currently-available short-stems.

To our knowledge, there is no comparative biomechanical study that examines differences regarding load transfer between these prostheses.

Both stems are regarded as reliable in terms of survivorship *(10)*. Furthermore, both prostheses seem to achieve proximal load transfer, an important feature of short-stemmed prostheses *(10,12,24,24,35)*.

This study investigated the influence of varus/valgus positioning of the Nanos® and Metha® prostheses on the development of bone mineral density (BMD) of the proximal femur.

PATIENTS AND METHODS

Nanos® (n= 51) or Metha® (n= 24) prostheses were implanted in 75 coxarthrosis patients. The indications for surgery were primary coxarthrosis in 67 cases and secondary coxarthrosis in 8 cases. Of the latter, three cases were dysplasia, four were femoral head necrosis (FHN), and one was femoral head epiphysiolysis.

25 osteoarthritis patients received Nanos® short-stemmed prostheses (Smith & Nephew GmbH, Marl, Germany). These cases of a historical study were recruited from 65 patients receiving Nanos® stems at our institution in 2010 *(35)*.

Another study group of 50 consecutive patients undergoing THA for severe primary coxarthrosis were randomized to receive either a Metha**®** (24 patients) or a Nanos**®** (26 patients) stem *(4)*.

Exclusion criteria for both study groups were: patient age greater than 70 years, cortisone therapy, cancer, rheumatoid arthritis, diagnosis of osteoporosis, and/or other bone or connective tissue diseases.

Postoperatively, all patients were mobilized with full weight bearing. Study follow up visits were scheduled as FU (follow up) 1 after 3 months and as FU 2 at 12 months.

Anteroposterior (AP) radiographs of the affected hip taken preoperatively and at FU1 were evaluated to compare CCD (caput collum diaphyseal angle) *(21)*, height of the center of rotation (COR) (perpendicular distance between the line connecting the inter-teardrop line and the center of femoral / prosthetic heads), and femoral offset (horizontal distance between the mechanical axis of the femur and the center of the femoral / prosthetic heads) *(23)*. The postoperative CCD was calculated for both stems following a method described in a former study *(4)*.

Longitudinal migration and varus/valgus tilt for both short-stemmed implants were determined digitally by a single examiner comparing stem position in the initial postsurgical radiograph with that in the AP films at FU1 and 2 using Wristing® digital software. The methods used to measure longitudinal migration and tilt of the femoral stem were detailed in a former study *(4).*

Because these measurements may be influenced by different rotational positioning of the proximal femur, positioning aids were used routinely during AP radiographs and DEXA of the hip joint.

The measurement errors for femoral stem migration and angulation were assessed as 2 mm and 3°, respectively, using the Wristing® digital software. Therefore, femoral stem migration or tilt change was considered significant with respective differences of at least 2 mm or 3° *(4).*

In addition, the incidence of periprosthetic radiolucent lines (RL) captured on the AP x-ray pictures was correlated with Gruen zones *(17).* RL was defined as radiolucency of at least 1 cm length and 1mm thickness between the prosthesis and the surrounding bone *(33).*

Statistical analysis was performed with SPSS (IBM SPSS Statistics, Version 22, IBM Company). Significant differences for normal distributed data between different follow ups were explored by paired t-tests, and significant differences between different study groups (DEXA) by unpaired t-tests. When normal distributions were not present, the Wilcoxon and Mann-Whitney U Tests were performed. The hypothetical influence of CCD and stem type on postoperative BMD was analyzed by linear regression. Therefore, linear regression analysis was performed with BMD at FU2 as the dependent variable, and CCD and stem type as two metric variables. Additionally, preoperative BMD was set as covariate. The level of significance was defined as $p < 0.05$.

RESULTS

Pre and postoperative offset and COR did not differ significantly (Table I).

A significant increase of approximately 1.5 mm from POST to FU2 was identified on the measurements of the distance peak of the lesser trochanter – apex of the femoral component (migration measurement). Pre and postoperative CCD measurements also changed significantly. This difference was evident for both stem types

Table I. — Migration and alignment of femoral component CCD, Offset and COR

Time point of evaluation average n	**PRE** 75	**POST** **5 days** (sd = 1 day) 75	**FU 1** **98 days** (sd = 8) 75	**FU 2** **382 days** (sd = 30) 75
Distance „ab“ (mm) sd		53.4 7.4	54.8 $^{p=0.001+}$ 7.8	54.9 $^{p=0.001+}$ 8.0
Preoperative CCD and stem alignment (°)** sd	129 7	135 6	132 $^{p=0.012+}$ 6	132 $^{p=0.017+}$ 6
Pre- and postop. CCD Metha® (°) (n= 24) sd **Pre- and postop. CCD Nanos®** (°) (n= 51) sd	131 7 129 7	127 $^{p=0.001\#}$ 6 135 $^{p=0.001\#}$ 7		
COR (mm) sd	18.0 5	18.2 $^{p=0.7\#}$ 5		
Offset (mm) sd	45.5 8	45.2 $^{p=0.6\#}$ 8		

(Distance „ab“= “ peak of lesser trochanter – apex of femoral component = measurement of migration(4)
$^{\#}$ = result of paired t-test, $^{+}$ = result of paired t-test between POST and FU1/ FU2, PRE = preoperatively, POST = postoperatively, FU = follow-up, sd = standard deviation, stem alignment = varus/valgus (increased values indicate varisation of femoral component)(4), CCD = caput collum diaphysis angle, COR = centre of rotation, ** = Metha® and Nanos® group

(Table I). In contrast, preoperative CCD measures did not differ between the Metha® and Nanos® groups (Mann-Whitney U Test, $p = 0.33$).

Thirty-three radiolucent lines were found in 27 of 75 cases, 382 days postoperatively (FU 2). In 14 cases, a radiolucent line was located at the polished tip area of the prosthesis only, which was not considered a sign of impaired osseointegration.

There was no conspicuous pattern of radiolucent lines identified in cases with postoperative CCD < 125° or > 135° compared to the entire group (Table II).

Table II. — Occurrence of radiolucent lines

	All Cases (FU 2)	**CCD < 125°** (FU 2)	**CCD > 135°** (FU 2)
number of cases	**75**	**12**	**26**
Zone 1	10	1	3
Zone 2	0	0	0
Zone 3	0	0	0
Zone 4	14	1	5
Zone 5	3	0	2
Zone 6	0	0	0
Zone 7	6	2	1
Total	**33**	**4**	**11**

DEXA scans showed significant changes in zones 1, 2, 6, and 7 at FU 2 compared to postoperatively. In zones 1 (approx. -13%), 2 (approx. -3%) and 7 (approx. -7.8%), significant decreases were detected, while zone 6 (approx. + 6%) showed a significant increase (Figure 2) (Table III).

In cases with CCD < 125° at FU 2, DEXA analysis showed significant decreases in Gruen zones 1 (approx. -3%), 5 (approx. -9%), and 7 (-13%) in both stem types. In contrast, cases with CCD > 135° showed significant decreases in Gruen zones 1 (approx. -11%), 2 (approx. -3%), and 7 (-4%) at FU 2 (Tables IV and V).

Postoperative offset and COR differed significantly (t-test, $p = 0.007$) ; however, this difference was not present between pre- and postoperative measurements within the groups (paired t-test, CCD < 125°: $p = 0.6$ (offset), $p = 0.5$ (COR) ; CCD > 135° : $p = 0.06$ (offset), $p = 0.4$ (COR)) (Table VI).

Two patients (8%) showed intraoperative fissures, which were treated with cerclage as described in a previous publication *(36)*. No other complications occurred.

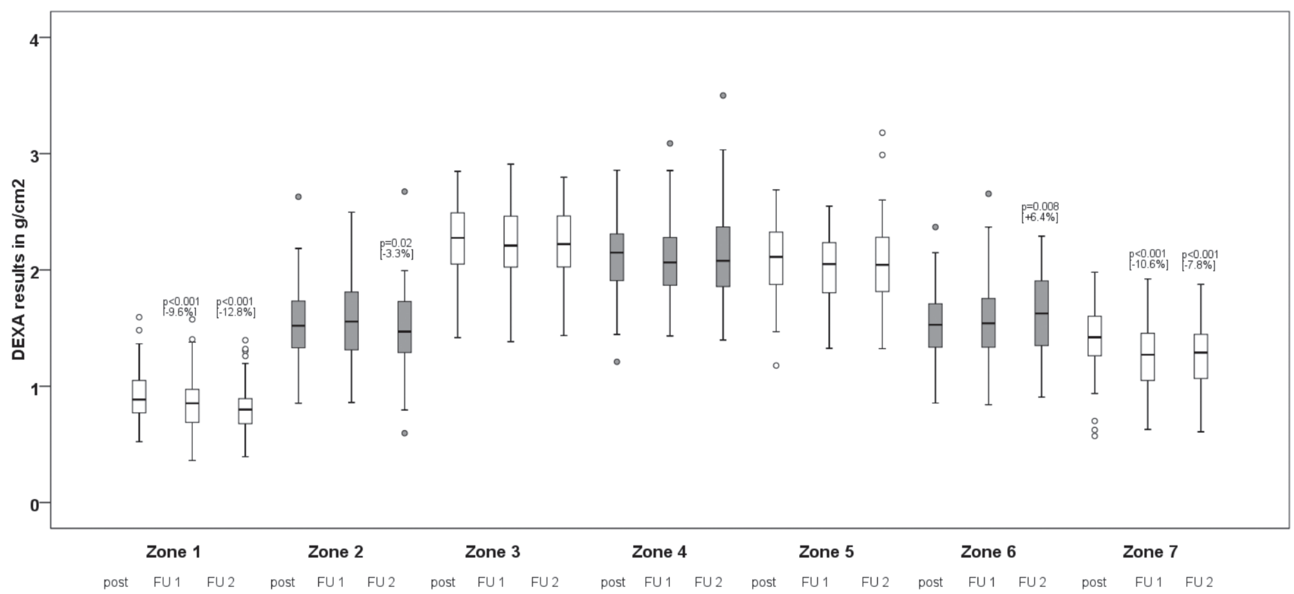

Fig. 2. — Box-Plot with DEXA results. (p= paired t-test, post= postoperatively, Zone= Gruen Zone)

DISCUSSION

This study analyzed bone remodeling around the Nanos® and Metha® stems as a function of varus/valgus stem positioning.

At FU2, DEXA scans showed significant decreases in Gruen zones 1 (approx. -13%), 2 (approx. –3%), and 7 (approx. -7.8%), and a significant increase in zone 6 (approx. + 6%).

These changes were interpreted as the consequence of moderate stress shielding of the proximal femur with significant but not exclusive proximal loading.

In cases with CCD < 125° of both stem types at FU 2, DEXA analysis revealed significant decreases in Gruen zones 1 (approx. -3%), 5 (approx. -9%), and 7 (-13%). In contrast, cases with CCD > 135° showed significant decreases in Gruen zones 1 (approx. -11%) and 2 (approx. -3%), and a comparably smaller decrease in zone 7 (-4%) at FU 2. We conclude that in our study, the DEXA measurements for prostheses inserted in valgus and varus positions show differing strain distributions.

Postoperative offset and COR differed significantly ; however, this difference was not present between pre- and postoperative measurements within the groups. Therefore it was considered that strain distribution was not influenced by these biomechanical parameters.

Linear regression analysis showed no prediction of BMD according to postoperative CCD or stem type. Thus, BMD is not significantly influenced by the CCD angle according to the range of postoperative CCD angles observed in the present study.

In summary, the DEXA scan evaluation showed evidence for significant proximally-located load transfer for both stems, as described in previously published studies *(24,24,35,36)*.

Short-stemmed prostheses are designed to attain physiological load transfer on the proximal femur, minimizing the effects of stress shielding and

Table III. — Results of DEXA

Gruen Zone	POST g/cm² (sd)	FU 1 g/cm² (sd)	FU 2 g/cm² (sd)
1	**0.94** (0.22)	**0.85** (0.23) p < 0.001 [-9.6%]	**0.82** (0.23) p < 0.001 [-12.8%]
2	**1.55** (0.37)	**1.53** (0.32) p=0.08	**1.50** (0.30) p=0.02 [-3.3%]
3	**2.24** (0.29)	**2.22** (0.29) p=0.2	**2.21** (0.43) p=0.2
4	**2.12** (0.31)	**2.07** (0.33) p=0.3	**2.10** (0.38) p=0.3
5	**2.08** (0.36)	**2.05** (0.33) p=0.6	**2.07** (0.34) p=0.2
6	**1.55** (0.31)	**1.58** (0.36) p=0.5	**1.65** (0.37) p=0.008 [+6.4%]
7	**1.41** (0.28)	**1.26** (0.29) p < 0.001 [-10.6%]	**1.30** (0.29) p < 0.001 [-7.8%]

(sd = standard deviation, [] = change in relation to POST)

Table IV. — Results of DEXA in cases with CCD POST < 125° (n= 12)

Gruen Zone	POST g/cm² (sd)	FU 1 g/cm² (sd)	FU 2 g/cm² (sd)
1	**0.81** (0.16)	**0.77** (0.20) p=0.19	**0.73** (0.76) p< 0.001 [-9.9%]
2	**1.33** (0.27)	**1.38** (0.34) p=0.13	**1.25** (0.28) p=0.4
3	**2.35** (0.28)	**2.31** (0.32) p=0.6	**2.22** (0.31) p=0.1
4	**2.14** (0.31)	**2.12** (0.34) p=0.4	**2.06** (0.38) p=0.09
5	**2.03** (0.32)	**2.00** (0.35) p=0.09	**1.88** (0.28) p=0.001 [-7.3%]
6	**1.59** (0.23)	**1.60** (0.25) p=0.9	**1.70** (0.24) p=0.3
7	**1.36** (0.28)	**1.19** (0.24) p<0.001 [-12.5%]	**1.20** (0.32) p=0.03 [-11.7%]

(sd = standard deviation, # = not significant (paired t-test, p > 0.05), [] = change in relation to POST)

Table V. — Results of DEXA in cases with CCD POST > 135° (n= 26)

Gruen Zone	**POST** g/cm² (sd)	**FU 1** g/cm² (sd)	**FU 2** g/cm² (sd)
1	**0.96** (0.20)	**0.85** (0.20) $^{p<0.001\ [-11.5\%]}$	**0.80** (0.15) $^{p<0.001\ [-16.6\%]}$
2	**1.75** (0.40)	**1.66** (0.30) $^{p=0.4}$	**1.62** (0.42) $^{p=0.03\ [-7.4\%]}$
3	**2.23** (0.27)	**2.20** (0.30) $^{p=0.23}$	**2.22** (0.40) $^{p=0.7}$
4	**2.08** (0.26)	**2.03** (0.35) $^{p=0.3}$	**2.05** (0.38) $^{p=0.6}$
5	**2.13** (0.25)	**2.11** (0.39) $^{p=0.9}$	**2.10** (0.32) $^{p=0.7}$
6	**1.54** (0.29)	**1.55** (0.35) $^{p=0..5}$	**1.55** (0.44) $^{p=0.8}$
7	**1.44** (0.21)	**1.31** (0.26) $^{p=0.007\ [-9\%]}$	**1.28** (0.31) $^{p=0.001\ [-11.1\%]}$

(sd = standard deviation, $^{\#}$ = not significant (paired t-test, p > 0.05), [] = change in relation to POST)

bone loss. This could be of importance, especially in younger patients, for whom preservation of metaphyseal bone stock is believed to result in improved options for revision surgery *(15).*

To evaluate strain distribution of short-stemmed implants, several DEXA-based observational studies of bone remodeling have been performed, yielding conflicting results regarding the attainment of selectively proximal load transfer *(4,6,15,22,24,24,25).* DEXA scans are generally accepted to evaluate osseointegration of femoral stems *(1,2,7),* and are regarded as an excellent method to analyze bone remodeling after the implantation of short-stemmed prostheses *(24).* DEXA is considered a precise method to measure small changes in BMD around femoral implants, and is seen as very reliable and unaffected by subjective error *(26,27).* Also, previous studies of conventional stems have concluded that maximum bone remodeling takes place 6 months after surgery and reaches a plateau after approximately one year *(26).* Further changes are due to long-term biomechanical adaptation and occur for another 1–2 years. Such changes are minor and show no substantial variation *(2,5),* which underscores the reliability of the duration of follow-up used in this study.

We found the proximal BMD loss observed after 12 months in both stem types to be significantly less than that reported for conventional prostheses, which has been quoted as high as 30% *(1,2).* Both stem types seem to prevent or at least reduce stress-shielding, and could therefore be regarded as therapeutic alternatives, in particular for younger patients. This statement is limited by the lack or limited availability of data concerning long-term results and especially long-term survival *(32).*

Statistical analysis of our data showed significant change of postoperative CCD for both stems included in this study. Floerkemeier et al. (2013) assessed the strain distribution for different resection heights of the Metha® prosthesis: at the recommended level, at minus 5mm, and plus 5mm, using strain gauges in synthetic bone to collect load transfer details. Therefore, strictly speaking, the strain pattern of different CCD implantation angles has been investigated, as the position of the Metha® stem was more valgus at the lowest and more varus at the highest resection height.

However, the simulation of recommended resection height, with preservation of a 5mm cortical ring of the femoral neck, showed only small differences. They concluded that depending on the anatomy and possible deformity of the proximal femur, a lower osteotomy seems to be appropriate to reconstruct the offset and limb length without major changes in strain patterns. *(11).*

Following Wolff`s law, one can expect a bone mass increase in cases of increased strain, whereas reduced load leads to bone atrophy *(13).* The response of bone mass around femoral stems has been shown to follow these principles, and this reaction is described as stress shielding *(14).* For conventional stems, different placement affects loading of the proximal femur, which might influence long-term bone remodeling *(18,18,20).* Therefore, one can assume that different stem positions of the Metha®

Table VI. — CCD, Offset and COR of cases with CCD < 125° and > 135°

	CCD < 125° n = 12	**CCD > 135° n = 26**
COR (mm)		
PRE	17.7	17.7 $^{p=0.7}$
POST	17.0	18.3 $^{p<0.001}$
OFF (mm)		
PRE	41.7	47.7 $^{p=0.06}$
POST	39.3	47.0 $^{p<0.001}$
CCD		
PRE	127	131 $^{p=0.2}$
POST	122	139 $^{p<0.001}$

PRE = preoperatively, POST = postoperatively, CCD = caput collum diaphysis angle, COR = center of rotation, OFF = Offset, p = result of unpaired t-test

Table VII. — Linear regression model

Gruen-Zone	**CCD**	**stem type**	**preoperative BMD**
1	p = 0.2	p = 0.5	p = 0.001
2	p = 0.8	p = 0.9	p = 0.9
3	p = 0.9	p = 0.7	p = 0.2
4	p = 0.9	p = 0.9	p = 0.2
5	p = 0.2	p = 0.8	p = 0.5
6	p = 0.8	p = 0.7	p = 0.008
7	p = 0.2	p = 0.9	p = 0.005

Linear regression analysis showed no influence of CCD or stem type on BMD in any of the Gruen zones at FU2.
BMD = dependent variable (FU2), CCD and stem type = possible predictors, preoperative BMD = covariate

and Nanos® prostheses resulting in different offsets should affect the loading pattern and therefore, stress shielding, after implantation.

The Nanos® short-stemmed prosthesis allows the modulation of offset with valgus or varus implant positioning. In theory, the offset for stem size 3 could be modified between 37mm to 65mm according to extreme varus or valgus stem insertion (Smith&Nephew, Marl, Germany).

Speirs et al. (2006) implanted a solid model of the Nanos® stem into a solid model of a standardized femur in neutral and varus positions to simulate various surgical insertions *(28)*. Proximal cortical strain varied by up to 22% according to implant position and was highest for varus placement.

Interestingly, these differences were relatively small compared to the overall change from measurements of the intact femur. Speirs et al. (2006) concluded that surgically-induced variations in stem offset, anteversion, and varus-valgus have relatively minimal influence on the overall changes in proximal femur loading and thus, on bone remodeling *(28)*.

In our study, the DEXA measurements for prostheses inserted in valgus and varus positions differed significantly. In varus, there seems to be increased loading of the medial aspect of the femur, whereas in valgus, reduced strain of the lateral aspect leads to an increase of stress shielding, as evident by decreased BMD. Overall, these changes were rather small as well, which supports the findings of Speirs et al. (2006) *(28)*.

We defined prostheses in < 125° stem position as valgus, and those in > 135° as varus. One must consider as well that there is no consensus regarding CCD range for varus, neutral, or valgus positioning for short-stemmed designs. Braun et al. (2009) defined the neutral zone for the Metha® between 130-140°. In contrast, Jerosch (2012) defined a CCD of 125° as standard for short-stemmed implants *(3,21)*.

Interestingly, pre and postoperative offset did not significantly differ in cases with CCD < 125° or >135° (paired t-test). Therefore, the changes in load transfer cannot be explained simply by differing strain axes of the femur as a result of implant position *(13,21)*. It is assumed that the strain distribution caused by differences in contact stress is induced by different implant positions *(21)*.

The main finding of this study was that BMD measured at FU 2 was not predicted by postoperative CCD. Of course, this conclusion can be considered exceptional because of the CCD angles and their distribution as measured in this study. It is unclear whether extreme stem positions could lead to effects other than those we observed. As expected, the preoperative BMD was identified as a covariate for some Gruen zones regarding postoperative BMD.

One possible explanation for the nonexistent correlation of BMD and postoperative CCD is the so-called "dead zone" of the mechanostat remodeling scheme, where no relevant bone response develops *(18)*. Obviously, both prostheses require an excessive change to the CCD to cause relevant under or overloading that would lead to increased bone renewal or formation. We must also consider that the mechanisms of tissue adaptation following changes to the loading conditions post-THA are not well understood. Subject-specific loading conditions and physiological boundary constraints are essential to explain interpatient variations in bone adaptation patterns *(30)*.

Measured stem migration and positioning changed significantly between FUs 1 and 2. In the case of migration measurement, the distance “ab” (peak of lesser trochanter – apex of femoral component) increased significantly between POST and FU 1 and between POST and FU 2. The average increases were 1.4 mm and 1.5 mm, respectively.

This difference is within the error margin of the measurement method, and clinically-irrelevant, as it is difficult to believe that a stem could “come out of the femur” when loaded.

The significant differences measured for stem positioning were regarded as not clinically-relevant, however, because they are small, within the measurement error of the Wristing® software (4), and because of the absence of clinical and other radiological signs of early stem loosening or failed osseointegration. None of the radiolucent lines exceeded 2mm width or 1.5cm length, and therefore were not considered signs of aseptic loosening *(37)*.

In conclusion, CCD after implantation of the Nanos® or Metha® prostheses exhibited no clinically relevant influence on BMD of the proximal femur. This conclusion is drawn exclusively for the range of postoperative CCDs observed in this study.

Varus positioning with CCD < 125° leads to increased medial loading with reduced stress shielding but increased lateral BMD loss. Valgus positioning with CCD > 135° induces increased stress shielding of the medial proximal femur and significant lateral distal load transfer. In summary, these changes are small and are probably less clinically-relevant than the magnitude of stress shielding found in conventional stems.

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