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ORIGINAL PAPER

Changes of periprosthetic bone density after a cementless short hip stem: a clinical and radiological analysis

Alexander Jahnke · Sandra Engl · Corinna Altmeyer · Eike Jakubowitz · Jörn Bengt Seeger · Markus Rickert · Bernd Alexander Ishaque

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Abstract
Purpose The purpose of this study was to examine the concept of proximal load initiation of a total short-stemmed hip arthroplasty (Metha® BBraun, Aesculap, Tuttlingen, Germany) on the basis of bone variations by means of osteodensitometric dual energy X-ray absorptiometry and radiologic measurements.
Methods After power analysis 40 patients were included in this study. DXA examination, radiological and clinical follow-up was performed pre-operatively and postoperatively. Socio-demographic relevancies of bone progression and radiological changes were raised epidemiologically and clinically.
Results Improvement of the Harris hip score from 54.7 points preoperative to 96.7 points postoperative was detected ($p<0.01$). Loss of summarized overall net average bone mass density (netavg BMD) could only be manifested after six months compared to the netavg BMD of the postoperative measurement ($p<0.01$). After six and 12 months BMD atrophy was shown mainly in regions of interest (ROI) 1, 4 and 7. Positive correlations between changes of BMD and age, male sex and BMI were detectable. No stem had to be revised.
Conclusions The Metha® implant shows excellent osseointegration at the coated area of the stem without factors of aseptic loosening in the short term. This study shows that parameters like age, sex and BMI influence BMD progression and stress shielding. Metha® implant shows excellent results especially in young patients with good bone stock.

Keywords DXA · Short stem · THA · Bone density · Densitometry

Introduction

Demographic processes and aging population reflect the necessity of total hip arthroplasty (THA). Even in young patients with congenital hip deformations THA can be provided [1]. This leads to more frequent revision surgeries for which adequate bone structure is absolutely necessary [2]. One of the main issues of THA is the load initiation into the femur. Implants lead to a changed physiological and biomechanical structure of the femur and thus the forces are modified. The bone responds to these changes by remodeling the bone structure [3]. Inadequate proximal load initiation into the femur leads to bone resorption and osteolysis at the proximal implant segment. Typical indices are atrophy of the calcar region and stress shielding at the region of the lesser trochanter which can result in aseptic loosening [4–7]. Therefore the most important gain of THA is to achieve a physiological load initiation and a good osseointegration of the prosthesis. Cementless implantation techniques favor a bone structure-saving implantation combined with a metaphyseal load transmission, which short-stem prostheses are designed for [8]. Many scientific investigations dealing with short- and mid-term results of short-stem prostheses justify optimism [8, 9]. However, long-term results have yet to be demonstrated.

The primary aim of this study was to examine the concept of proximal load initiation of the Metha® (BBraun, Aesculap, Tuttlingen, Germany) short-stem prosthesis by means of dual energy X-ray absorptiometry (DXA) and radiological measurements. Hypotheses were that (1) generally BMD atrophy occurs in all regions of interest (ROI) within six months, (2)

A. Jahnke · E. Jakubowitz
Laboratory of Biomechanics, Justus-Liebig-University Giessen, Paul-Meimberg-Strasse 3, 35392 Giessen, Germany

S. Engl · C. Altmeyer · J. B. Seeger · M. Rickert · B. A. Ishaque (✉)
Department of Orthopaedics and Orthopaedic Surgery, University Hospital Giessen and Marburg (UKGM), Klinikstraße 33, 35392 Giessen, Germany
e-mail: Bernd.Ishaque@ortho.med.uni-giessen.de

BMD atrophy arises at the proximal femur segment after 12 months and (3) BMD hypertrophy occurs at the coated area of the prosthesis. Other factors such as sociodemographic relevancies of bone progression and radiological changes were examined epidemiologically and clinically, which therefore led to the hypotheses that radiological changes and stress-shielding arise during the examinations (4). Further hypotheses that (5) there are correlations between BMD changes and age, BMI, diagnosis and sex and that (6) there is a clinical improvement of the symptomatology after implantation of the Metha® short-stem prosthesis after 12 months were set.

Patients and methods

Demographic data

From April 2010 to September 2011, 43 patients were consecutively recruited at the Department of Orthopaedics and Orthopaedic Surgery at the University Hospital Giessen and Marburg (UKGM). After positive vote by the ethic commission of the Justus-Liebig-University (Giessen, Germany) file number 152/09, unilateral implantation of the cementless Metha® short-stem prosthesis was performed in all patients. Inclusion criteria were primary or secondary osteoarthritis of the hip, avascular necrosis of the femoral head, epiphyseolysis capitis femoris (ECF), Morbus Perthes and age between 18 and 80 years. Exclusion criteria were osteoporosis (DXA T-Score <2.5), radiologically detectable osteoporosis, endoprosthetic or osteosynthetic treatment of the contralateral hip, abnormal deviations of the femoral neck (varus CCD <115°, valgus CCD >150° or coxa antetorta) and pathological fractures or fractures of the femoral neck. Three patients were excluded because of an endoprosthetic treatment of the other hip joint while the study was in progress. Among the 40 participating patients, 20 were female (50 %) and 20 male (50 %). The average age was 55.4 (27–77) years. The average body mass index (BMI) was 26.9 (18.0–36.7) kg/m². In 20 cases the left hip joint was operated and in 20 the right one.

Implants

In all patients the cementless monoblock Metha® short-stem prosthesis, developed for meta-diaphyseal fixation, was implanted. Based on its cone shape, its positioning in the femoral neck stump and its close fit at the dorsolateral cortex, this prosthesis design is said to provide a good primary stability and supports proximal load initiation. The implant's surface is coated with microporous dicalcium phosphate. The stem itself is made of titanium (Ti6Al4V) forged alloy.

Surgical technique

Preoperative planning was carried out by X-ray stencils. In all cases surgery was performed by an experienced surgeon (BA.I.) using the minimal-invasive anterolateral approach according to Frndak [10]. In two cases the lateral approach was performed according to Bauer [11] because of prior surgeries of the treated hip side. All patients were allowed full weight bearing two days postoperatively.

Clinical examination

For clinical evaluation the modified Harris hip score (HHS) [12] was applied preoperatively and three, six and 12 months after surgery.

Osteodensitometric examination

DXA scans were performed by the Lunar Prodigy Primo device and metallic artifacts were eliminated by the specific Orthopedic Hip Software (GE Medical Systems, Madison, Wisconsin, USA). In order to avoid rotational errors [7], patients were bedded in supine position and standardized use of two positioning aids put the hip joints in neutral position. As a reference a postoperative measurement of the treated hip side was performed within the first postoperative week (t_1) [7, 13]. Additional follow-up controls were performed after six (t_2) and 12 months (t_3). One patient was lost to t_1, but could be re-included at t_2. Another patient withdrew at t_2. DXA scans started 2 cm below the prosthetic tip and ended 4 cm above the greater trochanter. The prosthetic side was divided into seven ROI following the modified classification according to Gruen [4] (Fig. 1). Data are presented as mean averages of bone mass density (BMD) [g/cm^2] of ROI 1–7 and as summarized overall net average bone mass density (netavg BMD) [g/cm^2] of all zones.

Radiological examination

Pre-operatively, postoperatively and after three, six and 12 months radiological examinations were carried out. For this purpose radiographs of the pelvic area and Lauenstein-projections of the treated hip side were taken. By means of the pre-operative image diagnosis, the quality of the femur was defined, followed by a modified classification of the radiograph according to Gruen [4] for recording changes of the bone stock. The pre-operative radiographs were calibrated with a magnification factor of 1.15. Postoperative images were

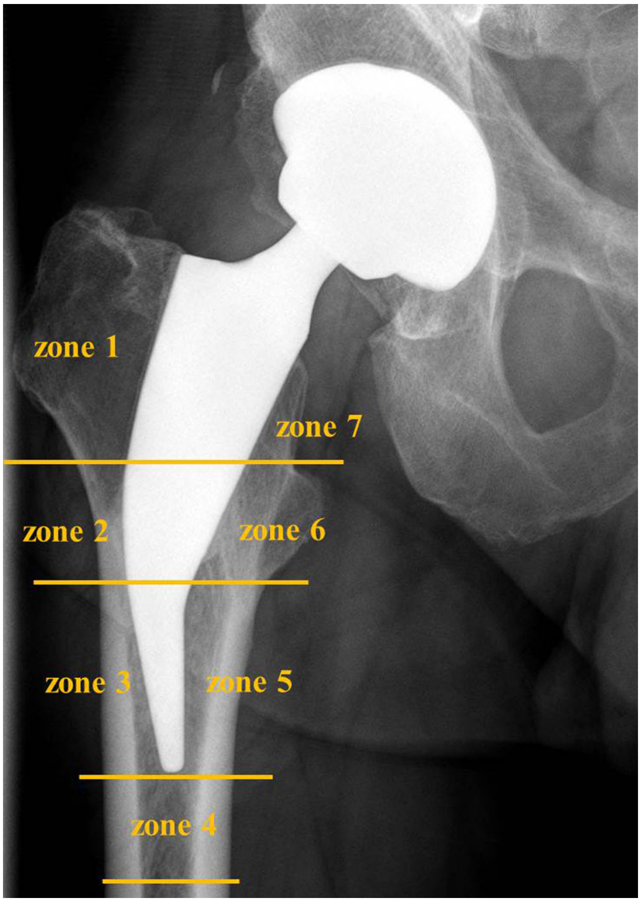

Fig. 1 ROIs according to Gruen zones 1–7

calibrated on the prosthetic head size. For quality assessment, phantom measurements were performed on a daily basis. The implant was regarded as stable if there were no additional formations of sclerotic margins by existent pedestal formations [5]. According to this, periprosthetic reactive lines at the coated prosthetic areas are defined as non-osseointegration, in the following defined as loosening factor [4]. Reactive lines at the distal and uncoated stem segment are no criteria of instability.

Statistics

Statistical analysis was performed by a linear regression model with repeated measures ANOVA (analysis of variance) using the software SPSS version 22.0 (IBM Corporation, New York, USA). Correlations between BMD changes and potential factors like treated hip side, sex, age, diagnosis, BMI, HHS and changes of the radiological examinations were raised and Pearson's chi-square test was applied. A p value of <0.05 was defined as statistically significant. For descriptive analysis of BMD changes, mean average BMD changes of ROI 1–7 and netavg BMD are presented as difference of both absolute and relative values (%) referred to the measurement at t_1. To characterize the bone growing progression behavior changes between t_2 and t_3, mean average BMD of zones 1–7 and netavg BMD were examined additionally. Due to multiple testing, only netavg BMD changes of t_2 and t_3, referred to t_1 and between t_2 and t_3, were interpreted as convincing results.

Results

Clinical results

The HHS improved with a mean of 57.4 pre-operatively to a mean of 89.7 after three months. After six months "excellent" results with a mean of 93.4 points could be seen. These results increased to a mean of 96.7 points after 12 months. This change was highly significant compared to pre-operative scores ($p<0.01$).

Osteodensitometrical results

At t_1 loss of bone density could be shown in ROI 1 (−8.8 %), 2 (−2.1 %), 3 (−1.2 %), 4 (−2.4 %), 5 (−1.2 %) and 7 (−7.8 %). Increasing bone density could only be shown in ROI 6 (+ 2.5 %). Highly significant bone loss of netavg BMD could only be manifested at t_2 compared to t_1. At t_3 bone loss was also shown in ROI 1 (−8.0 %), 4 (−1.8 %) and 7 (−11.4 %). Increasing bone density could be shown in ROI 2 (+6.1 %), 3 (+3.3 %), 5 (+2.1 %) and 6 (+5.9 %) (Table 1). Bone progression between six and 12 months ($\Delta t=t_3-t_2$) showed slightly increasing BMD in ROIs 1 (+0.9 %), 2 (+8.3 %), 3 (+4.5 %), 4 (+0.6 %), 5 (+3.3 %) and 6 (+3.3 %). Only at ROI 7 bone loss between six and 12 months was evident (−3.9 %). Overall netavg BMD changes slightly increased around +2.7 %.

Radiological results

Radiolucent lines were only noticeable at ROI 3–5 at the distal portion of the prosthetic stem after 12 months. Reactive lines were manifested at ROI 3–5 after six and 12 months. Cortical hypertrophy could be shown at ROI 2 and 3, which is the lateral diaphyseal area, after six and 12 months. No pedestal formations of the cohort were visible. During each follow-up control, trabecular structures were evident at ROI 2 and 3, the lateral diaphyseal area, and at ROI 6 which is the medial diaphyseal area (Table 2).

According to Engh [5] no higher stress shielding grades were evident throughout the cohort. After six months, 11 patients and after 12 months eight patients showed no stress-shielding (scale 0). Calcar rounding (scale 1) was noticeable in 24 patients after six and also in 24 patients after 12 months.

Table 1 BMD measurement results of ROI 1–7 and netavg BMD of all ROI [g/cm^2] at t_2 and t_3 compared to t_1. BMD changes of all ROI 1–7 and netavg BMD changes between t_2 and t_3 ($\Delta t=t_3-t_2$) are shown to characterize the bone growing progression behavior changes

	t_1	t_2			t_3			$\Delta t=t_3-t_2$	
Gruen zone	BMD [g/cm²]	BMD [g/cm²]	mean change	p-values	BMD [g/cm²]	mean change	p-values	mean change	p-values
ROI 1	0.83	0.76	−0.07 (91.2 %)	0.32	0.76	−0.07 (92.0 %)	0.44	0.01 (100.9 %)	0.41
ROI 2	1.41	1.38	−0.03 (97.9 %)	0.48	1.50	0.09 (106.1 %)	0.41	0.12 (108.3 %)	0.45
ROI 3	2.15	2.12	−0.03 (98.8 %)	0.48	2.22	0.07 (103.3 %)	0.51	0.10 (104.5 %)	0.48
ROI 4	2.07	2.02	−0.05 (97.6 %)	0.48	2.04	−0.04 (98.2 %)	0.42	0.01 (100.6 %)	0.54
ROI 5	1.88	1.85	−0.02 (98.8 %)	0.45	1.91	0.04 (102.1 %)	0.48	0.06 (103.3 %)	0.45
ROI 6	1.39	1.42	0.03 (102.5 %)	0.35	1.47	0.08 (105.9 %)	0.47	0.05 (103.3 %)	0.45
ROI 7	1.30	1.20	−0.10 (92.2 %)	0.35	1.15	−0.15 (88.6 %)	0.38	−0.05 (96.1 %)	0.48
netavg	1.57	1.54	−0.04 (97.6 %)	<0.01**	1.58	0.00 (100.2 %)	0.08	0.04 (102.7 %)	0.08

t_1, within the first postoperative week; t_2, after six months; t_3, after 12 months

After six months, four patients and after 12 months seven patients showed calcar rounding in combination with cortical bone density resorption at ROI 1.

Correlations

Table 3 shows significant correlation factors of BMD changes for the male sex ($p<0.001$). Correlations between BMI and BMD changes after 12 months could be seen ($p=0.024$, $R=0.36$). Any other factors proved no significant relevancies of BMD changes. Diagnosis for the treatment was directly influenced by the advanced age of the cohort ($p=0.016$, $R=-0.38$), and BMI in males was significantly higher than in female patients ($p=0.038$).

Discussion

Short-stem prostheses have been proven clinically [9], but this is the first study focusing on the Metha® short-stem prosthesis being examined osteodensitometricaly, clinically, radiologically and epidemiologically. DXA examination is a proven [13] and very precise [14] method to show bone remodeling changes. Many investigations dealing with remodeling processes after cementless THA had been carried out with other prosthetic designs [7, 13–19], but for the first time these processes now have been investigated for a greater patient cohort for the Metha® short-stem prosthesis. To ensure qualitatively valuable conclusions of remodeling [7], this study was performed prospectively within an examination period of 12 months because most of the dynamic remodeling processes are determinable within one year [20].

One hypothesis of the present study was that generally BMD atrophy occurs in all ROIs within six months postoperatively (1). Another hypothesis was that periprosthetic BMD atrophy arises at the proximal femur segment after 12 months (2). BMD atrophy mainly appears in ROI 1, 4 and 7 after six months as well as after 12 months. Comparable studies dealing with short-stem prostheses could also demonstrate that atrophy of BMD mainly occurs in the proximal ROIs 1, 6 and 7 and hypertrophy of BMD in the lateral ROIs [9, 17, 21], so the results of this study are almost similar. Observation

Table 2 Total quantities of radiologically detectable changes at the particular Gruen zones of the cohort after three, six and 12 months (M)

	Clarification			Reactive lines			Cortical hypertrophy			Pedestal formation			Trabecular structures		
Gruen zone	3M	6M	12M	3M	6M	12M	3M	6M	12M	3M	6M	12M	3M	6M	12M
ROI1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
ROI 2	–	–	–	–	–	–	–	1	1	–	–	–	1	3	15
ROI 3	–	–	3	–	1	1	–	3	4	–	–	–	–	–	2
ROI 4	–	–	6	–	1	1	–	–	–	–	–	–	–	–	–
ROI 5	–	–	4	–	1	1	–	–	–	–	–	–	–	–	–
ROI 6	–	–	–	–	–	–	–	–	–	–	–	–	1	10	24
ROI 7	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

Table 3 Influencing factors of BMD changes

	p-values		
Factor	t_1	t_2	t_3
Treated hip side	0.497	0.418	0.364
Sex	$<0.001^{**}$	$<0.001^{**}$	$<0.001^{**}$
Diagnosis	0.908	0.523	0.974
BMI	0.086	0.059	0.024^{*}
Age	0.229	0.662	0.239
HHS	0.924	0.612	0.216
		p-values	

t_1, within the first postoperative week; t_2, after six months; t_3, after 12 months. Asterisks indicate statistical significance

of BMD changes after six and 12 months showed that hypertrophy bone remodeling processes primarily occurred at ROI 6 (lesser trochanter region) and bone atrophy consequently at ROI 7 (proximal calcar). This might result from stress-shielding of the proximal femur due to the great proximal cross-section of the implant [15]. Significant netavg BMD atrophy occurred after six months and therefore pointed out great dynamic remodeling processes within the first follow-up period. These remodeling processes were nearly stabilized within 12 months which might therefore be a criterion for the good fixation behavior of the Metha® short-stem prosthesis. However, significant netavg BMD loss after six months may be caused by blood-flow disorders resulting from the surgical femoral preparation [19]. Bone growing at ROIs 2, 3, 5 and 6 could result from a good migratory behavior of the prosthesis because of its coated area, for example, which therefore supports our hypothesis (3). This can be interpreted as a sign of reliable osseointegration of the Metha® prosthesis. However, ROI 7 indicates progressive atrophy tendencies. This could also be due to lateral load initiation. Hence long-term studies have to evaluate the migration behavior. In summary, bone atrophy processes can occur at the proximal segment of the prosthesis for both types of prosthesis: straight standard or short stem.

In this collective the occurrence of reactive lines could only be observed in one case in zones 3, 4 and 5 at the uncoated parts of the prosthesis, which is no sign of implant instability [5]. Only slight characteristics of clarification in zones 3, 4 and 5 were visible [4]. Reactive lines and clarifications at the coated part of the stem could be an indication of insufficient osseointegration and thus, point out aseptic loosening of the prosthesis [6]. In this study these radiological changes were only seen at the uncoated parts of the stem. Thus we conclude that there is no loosening of the Metha® prosthesis. Trabecular structures could mainly be found in zones 2, 6 and at the lower portions of the coated area of the stem. These occurrences could be found in several studies [16, 22] which indicate a good osseointegration of the prosthesis. As correlation of the macroscopicly-proven trabecular structures, the osteodensitometrical examination indicates BMD hypertrophy in zone 6, which leads to the conclusion of increased medial bone loading of the prosthesis [5]. This is a sign of good osseointegration at the medial coated area of the prosthesis. Calcar rounding is a sign of reduced loading of the proximal femur and is interpreted as stress shielding [18]. Lerch et al. presented similar results [16]. For the time being it is difficult to estimate how stable the prostheses will remain despite calcar atrophy. Long-term studies have to demonstrate this, although hypothesis (4) has been proven true.

One additional hypothesis of the present study was that there are correlations between BMD changes and age, BMI, diagnosis and sex (5). Radiological and osteodensitometric examinations demonstrate atrophy of BMD in the proximal segment of the prosthesis. However, good osseointegration in the middle area of the coated prosthesis portion and no signs of aseptic loosening are noticeable, which suggests good migration of the Metha® short-stem prosthesis. BMD changes do not directly correlate with clinical outcomes despite significant improvements of HHS.

A limitation of our study is a relatively small cohort size. Nevertheless, DXA measurements are time consuming and this is the first Metha® study correlating DXA measurement with radiological, epidemiological and clinical data. We agree that 12 months is a short follow-up period for clinical results. Since most of the dynamic remodeling processes are determinable within one year [21], this short follow-up is sufficient to evaluate any correlations. However, long-term studies have to be carried out.

Conclusion

This study shows that parameters like age, sex and BMI influence bone mineral progression and rate of stress shielding. Even though correlations between age and progression of BMD changes could not be established [13], this study demonstrates that more BMD changes may occur with older patients. Furthermore, positive influence of BMD is higher in males than females. The Metha® implant shows excellent results especially in young patients with good bone stock.

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

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