Comparison of periprosthetic bone mineral density between two types of short-stems in total hip arthroplasty with a mean follow-up of 4 years

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Original article

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Abstract

Introduction:

The use of short stems in primary hip arthroplasty has grown considerably in recent years, with a large variety of designs and stabilization methods available. Few studies have directly compared how these designs and fixation modes influence the bone mineral density (BMD) that is said to be better preserved with shorter implants. This led us to carry out a medium-term retrospective comparative study to 1) specify how the design of two different types of short stems influences the periprosthetic BMD, 2) compare the radiological and clinical outcomes of these stems.

Hypothesis:

The periprosthetic BMD of a short stem varies based on the implant's design.

Materials and Methods:

Ninety-three patients underwent total hip arthroplasty (THA) with a short stem between July 2012 and July 2014. Two groups of patients were formed: Vitae™ short stem (Adler Ortho, Milan, France), Optimys™ short stem (Mathys, Bettlach, Switzerland). The Vitae group consisted of 46 patients, while the Optimys group consisted of 47 patients. The mean age was 66 years, and the mean body mass index (BMI) was 26 kg/m^2. The groups had comparable age, BMI, sex, Harris Hip score and preoperative radiological features. Periprosthetic BMD of the two types of implants was determined between the 1st and 4th year postoperative using dual-energy x-ray absorptiometry (DEXA) in the Gruen zones. The radiological and clinical outcomes were also determined.

Results:

There was a significant decrease in BMD in zone 7 (−5.8% ± 0.1 $CI_{95\%}$[−0.09; −0.02] (p=0.003)), zone 2 (−4.8% ±0.1 $CI_{95\%}$[−0.093; −0.003] (p=0.038)) and zone 6 (−11% ±0.2 $CI_{95\%}$[−0.19; −0.03] (p=0.009)) in the patients with Vitae stems and in zone 2 (−13.7% ± 0.3 $CI_{95\%}$[−0.25; −0.03] (p=0.018)) in the patients with Optimys stems. A significant difference in BMD in zone 7 at 1 year (p=0.014) and 4 years (p=0.001) postoperative and in zone 6 (p=0.011) at 4 years postoperative existed between groups, with the Optimys group having higher BMD. There was a significant increase in femoral offset in the Optimys group but not the Vitae group: Δoffset= –0.50 mm ± 5.2 $CI_{95\%}$[−2.05; 1.05] (p=0.522) and Δoffset = 2.79 mm ± 4.2 $CI_{95\%}$[1.21; 4.37] (p=0.001). The Harris Hip score was not significantly different between the two groups at 4 years postoperative (95.3 ± 2.5 [88; 99] vs 95.2 ± 2.6 [88; 99] (p=0.991)).

Discussion:

The design of short stems appears to influence the distribution of loads and the periprosthetic BMD. These stems are associated with very good radiological and clinical results in the medium term. Bone remodeling appears to continue beyond 1 year after the THA procedure.

Level of evidence: III; Retrospective case-control study

Keywords: short stem, bone remodeling, Gruen zone, dual-energy X-ray absorptiometry

1. Introduction

Total hip arthroplasty (THA) yields excellent long term clinical outcomes, making this one of the most frequently performed surgical procedures in the world. Its main drawback is its limited lifespan [1]. The design of THA implants has greatly evolved in recent years. However, their bone fixation can sometimes be non-physiological, leading to periprosthetic bone resorption and contributing to aseptic loosening of the implants [2,3]. This phenomenon contributes to 75% of long-term THA revisions, and is the most common reason that primary THA procedures fail [4]. Short-stem THA systems have been developed to counter this phenomenon by improving force transmission and preserving the bone stock [5].

Several types of short stems are available that have different designs and fixation modes [6,7]. The radiological outcomes differ in the literature, with studies reporting either an increase or decrease in bone mineral density (BMD) at the calcar, evidence that the load transfer is unique to each stem [8,9]. These concepts are controversial. To our knowledge, few studies have compared how the BMD changes between two short stems.

This led us to carry out a retrospective comparative study to 1) analyze two types of short stems (Vitae™ stem, Adler Ortho, Meyreuil, France, and Optimys™ stem Mathys, Bettlach, Switzerland) to determine whether their design affects the periprosthetic BMD at a mean follow-up of 4 years; 2) compare the radiological and clinical outcomes (functional scores, stem subsidence, restoration of femoral offset and leg length) of THA procedures done with these two stems. The hypothesis was that the BMD in the proximal femur will differ depending on which design and type of short stem is used.

2. Materials and methods

2.1 Patients

This was a retrospective, comparative, single-center study performed at the Amiens-Picardie University Hospital. It was approved by the hospital's ethics committee (study registration ID RCB: 2018-A02507-48). Included were all patients who underwent THA with a short femoral stem between July 2012 and July 2014 (Figure 1). Exclusions were any surgical indication other than advanced primary hip osteoarthritis, previous surgery on the involved hip, long-term corticosteroid therapy, or osteoporosis.

In all, 116 patients were eligible for the study. After applying the exclusion criteria, 46 hips implanted with the Vitae™ stem were compared to 47 hips implanted with the Optimys™ stem (Figure 1). The mean follow-up was 50 months [41-62]. Demographic data for the two groups are shown in Table 1. There was no significant difference between the two patient groups in their age, BMI, sex, Harris Hip score and preoperative radiological features.

2.2 Methods

Patients were operated by two experienced surgeons after preoperative planning on radiographic templates (100% scale). Written consent was obtained from all study participants. Two types of stems were used:

- Groupe 1: The Vitae™ which is a straight cementless stem with metaphyseal fixation, modular neck, that is made of titanium alloy with a highly porous surface (pore diameter 700 microns, porosity of 65%) (Figure 2). A ceramic–ceramic bearing was used: composite ceramic head and liner (Biolox delta™, Ceramtech, Plochingen, Germany). A cementless Fixa-Tipor™ cup (Adler Ortho, Milan, Italy) was used that had a 2 mm extra-thickness peripheral press-fit. This cup is manufactured from titanium alloy using the same process as the stem. The modular neck was also made from titanium alloy. A minimally invasive posterolateral approach was used for THA.

- Group 2: Optimys™ stem that has a fixed neck, anatomical curvature and conical shape, available in two offsets (standard or lateralized +5 mm). The philosophy behind this short stem is to reproduce the femur's medial curvature with the goal of restoring the center of rotation and femoral offset, in accordance with the patient's original neck-shaft angle. The stem has a bilayer coating (rough titanium layer with 20% to 40% porosity, which is then covered by a calcium phosphate layer). Its distal tip is polished and rounded (Figure 2). A polyethylene–metal bearing was used. The cup was the RM Pressfit™ (Mathys Ltd, Bettlach, Switzerland). This is an elastic monoblock cementless implant made of highly cross-linked polyethylene covered by a thin layer of titanium particles. The minimally invasive anterolateral (Röttinger) approach was used.

2.3 Assessment methods

The primary endpoint was the change in periprosthetic BMD between postoperative years 1 and 4. The secondary endpoints were various clinical, functional and radiological outcomes. The data were collected by an independent investigator (AE).

The periprosthetic BMD was determined by dual-energy x-ray absorptiometry (DEXA) at 1 and 4 years postoperative. The BMD was determined with the Hologic Discovery system (HOLOGIC, QDR DISCOVERY W, Hologic, Villepinte, France). The patient's positioning, amount of leg rotation and scanning protocol were standardized. The contralateral hip was analyzed in every patient to use as a reference. The seven modified Gruen zones were analyzed [11,12] (Figure 2). The BMD is expressed in g/cm^2. The various measurements were added to provide an overall periprosthetic BMD at 1 year and 4 years postoperative that can be compared with the contralateral leg. BMD changes were determined by comparing the mean BMD at 1 year to the mean BMD at 4 years. The change was expressed as a percentage relative to the initial value.

The clinical outcomes consisted of the Harris Hip score (preoperative and final follow-up) [10] and postoperative complications. The radiological analysis was done using standardized radiographic views: AP pelvis, AP hip and lateral hip. An acceptable radiograph was defined by a coccyx centered on the pubic symphysis, with the two legs turned internally 15° with the bony landmarks (pelvic tear-drop and lesser trochanter) clearly visible. The radiographs were calibrated based on the ratio between the measured diameter of the replacement head relative to its known diameter. We measured the femoral offset using the Kutzner method [13] (Figure 3), potential leg length discrepancy (distance between line passing through the pelvic tear-drop and line passing through the lesser trochanters), presence of radiolucent lines and their progression, potential stem subsidence (distance between tip of greater trochanter and the stem's shoulder) and varus positioning of the femoral stem (variation in the angle between the shaft axis and the stem axis). Loosening was defined as the presence of a progressive radiolucent line more than 2 mm. Migration was considered as significant when the subsidence was more than 3 mm, or the varus shift was more than 3°. Lastly, we measured the cortical thickness index (CTI) [14] to determine the BMD of the proximal femur on both legs on preoperative radiographs. All the radiographic measurements were done using the DxMM® software (MedaSys, Dedalus, France) by a single investigator (AE).

2.4 Statistical analysis

The data were expressed as mean and standard deviation values. The normality of the distribution was determined using the Shapiro-Wilk test. The results for each short stem were compared using Student's *t*-test for independent variables. Within-group comparisons at different moments in time were done with a Student's *t* test for paired data. Qualitative variables were compared using the Chi-square test. Missing data were imputed by the mean value. Data analysis was done using SPSS Statistics software (version 24, IBM Corp, Armonk, NY, USA). A *p* value of 0.05 or less was considered significant.

3. Results

In the Vitae stem group, there was a significant decrease in BMD between postoperative years 1 and 4 in zone 7 (−5.8% ±0.1 $CI_{95\%}$[−0.09; −0.02] (p=0.003)), zone 2 (−4.8% ±0.1 $CI_{95\%}$[−0.093; −0.003] (p=0.038)) and zone 6 (−11% ±0.2 $CI_{95\%}$[−0.19; −0.03] (p=0.009)). There was no significant difference in the other zones (Table 2).

In the Optimys stem group, a significant decrease of BMD was found only in zone 2 (−13.7% ±0.3 $CI_{95\%}$[−0.25; −0.03] (p=0.018)). The changes in BMD were not significant in all the other Gruen zones, including zones 6 and 7 (Table 3).

There was a significant difference in the mean BMD between the two groups in zone 7 at 1 and 4 years, along with zone 6 at 4 years (Table 4). There was no significant change in BMD of the contralateral hip in either group at 1 year or 4 years postoperative.

Using the contralateral hip's BMD as a reference value, the overall BMD at 1 year postoperative was significant higher in the operated hip: 0.91 ±0.1 $CI_{95\%}$[0.86; 0.97] vs 1.19 ±0.2 $CI_{95\%}$[1.11; 1.27] (+28%) ($p<0.0001$) for the Vitae stem and 0.93 ±0.1 $CI_{95\%}$[0.87; 0.98] vs 1.17 ±0.14 $CI_{95\%}$[1.11; 1.23] (+25%) ($p<0.0001$) for the Optimys stem. At 4 years postoperative, the operated hip also had higher BMD overall than the contralateral hip: 0.91 ±0.1 $CI_{95\%}$[0.85; 0.96] vs 1.18 ±0.2 $CI_{95\%}$[1.13; 1.29] (+30%) ($p<0.0001$) for the Vitae stem and 0.93 ±0.1 $CI_{95\%}$[0.88; 0.98] vs 1.17 ±0.1 $CI_{95\%}$[1.12; 1.23] (+24%) ($p<0.0001$) for the Optimys stem.

In both groups, the Harris Hip score improved significant between the preoperative measurement and the final assessment: 57.5 vs 95.3 ($\Delta H=37.8 \pm 5.2$ $CI_{95\%}$[36.3; 39.3]) ($p<0.001$) for the Vitae stem and 58.7 vs 95.2 ($\Delta H=36.5 \pm 5.0$ $CI_{95\%}$[34.6; 38.4]) ($p<0.001$) for the Optimys stem. There was no significant difference between groups in the mean Harris Hip score at 4 years postoperative: 95.3 ± 2.5 [88; 99] for the Vitae stem versus 95.2 ± 2.6 [88; 99] for the Optimys stem ($p=0.991$).

As for complications, one obese patient (BMI =36.5 kg/m^2) in the Vitae group reported having thigh pain at 1 year postoperative; this pain was eliminated after a treatment with step II analgesics (Monocrixo (tramadol chlorhydrate) 150mg LP at night with breakthrough doses of Ixprim (tramadol chlorhydrate + paracetamol)). One patient in the Vitae group underwent early revision to change the neck length after two dislocation episodes; he was excluded from the study and did not have any BMD measurements taken (Figure 1).

The preoperative CTI values were comparable between the two groups (0.57 ± 0.06 [0.43; 0.71] vs 0.60 ± 0.06 [0.50; 0.74] ($p=0.099$)) and also between the operated and contralateral hip (0.58 ± 0.06 $CI_{95\%}$[0.57; 0.60] vs 0.58 ± 0.06 $CI_{95\%}$[0.57; 0.60] ($p=0.187$)). There was also no significant difference in the leg length discrepancy between the two groups (−0.4 mm ± 1.4 [−4.6; 2] vs −0.3 mm ± 1.6 [−3.7; 3.1] ($p=0.849$)). The preoperative femoral offset was comparable between the two groups (46.4 mm ± 7.9 [31.4; 64.9] vs 46.4 mm ± 5.5 [35; 56] ($p = 0.853$)). There was a significant increase in femoral offset between the preoperative and postoperative measurement only in the Optimys stem group: Δoffset=−0.50 mm ± 5.2 $CI_{95\%}$[−2.05; 1.05] ($p=0.522$) in the Vitae stem group and

Δoffset = 2.79 mm ± 4.2 $CI_{95\%}$[1.21; 4.37] (p=0.001) in the Optimys stem group. There was a significant difference between groups in the postoperative femoral offset, which was higher in the Optimys group than the Vitae group (49.2 mm ± 6.2 [33.1; 60.2] vs. 45.9 mm ± 6.3 [32; 58] (p=0.049)). There were no radiolucent lines or periprosthetic fractures in either group at 4 years' follow-up. There were three instances of subsidence with varus shift (> 3 mm and 3 degrees) and one isolated subsidence of the femoral stem in the Vitae group (> 3 mm) versus two instances of subsidence (> 3 mm) in the Optimys group.

4. Discussion

Various short stems exist that have different biomechanical properties and fixation modes, which appears to affect periprosthetic bone turnover. Our study hypothesis was verified since the design of the Optimys™ appears to better limit the stress-shielding phenomenon than the design of the Vitae™ stem. A classification of short stems was proposed at the 2018 symposium of the SFHG [15], based on the neck cut and fixation mode. Five categories were made to describe the stabilization point: head, neck, contact against the Merkel's spur, metaphyseal or metaphyseal–diaphyseal. The stems in our study fall in the third (Optimys™) and fourth categories (Vitae™). Stems that require only partial neck resection appear to be better because more bone stock is preserved and there is an option to make a cut that will better restore the patient's specific femoral offset [16].

We found that the patients who received the Optimys stem did not have reduced BMD in zones 6 and 7, which appears to be due to this implant's design. This stem has an anatomical medial curvature that rests against the calcar's curvature and the medial cortex, contributing to physiological load distribution [15,17]. The stem's distal end will rest against the lateral or medial cortex, depending on the femur's shape, contributing to primary stability and osseointegration. In the Vitae stem group, the stem's design does not impose positioning with medial cortical contact, which may explain the BMD findings of significant reduction in BMD in zones 2, 6 and 7. However, there was no significant difference in the overall BMD between the two groups at 1 year or 4 years postoperative. This could be explained by the fact that both stems belong in the group of THA implants requiring conventional neck resection in the Falez classification [5] and that their design requires following along the calcar when they are inserted.

DEXA is an excellent tool for evaluating the periprosthetic bone stock [18]. Some authors have found a correlation between BMD and the clinical outcomes of THA, suggesting that this measurement is a predictor of the implant's longevity [19]. The BMD results for short stems are clearly better than those of standard femoral stems [20-21]. An analysis of the literature is difficult because studies vary in the length of follow-up, type of stem studied and the reference measurement used (contralateral hip, preoperative BMD, BMD at 1 week postoperative). However, there appears to be a consensus about the reduction in BMD in zones 1, 2, 6 and 7, which is less than what we find with a standard stem [22–29] (Table 5). At 2 years, Shafy et al. [31] found a non-significant reduction in periprosthetic BMD in zones 1 and 7 for the MiniHip™ (Corin, Cirencester, UK). Freitag et al. [32] identified a reduction predominantly in zones 6 and 7 with the Fitmore™ stem (Zimmer, Warsaw, Indiana, United States) that is significantly less compared to standard straight stem from the same manufacturer. While Gasbarra et al. [30] found a significant increase in BMD in zones 1 and 7 for the same stem at the same time point. In a recent systematic review, Yan et al. [33] compared different types of stems and showed preservation of the proximal bone stock with short stems and highly variable bone turnover depending on the stem's design.

Our clinical outcomes for THA with short stems are comparable to published results with excellent functional scores and overall survival. Our medium term results are comparable to studies of standard non-cemented femoral stems as well as studies with short stems [34,35]. From a radiological point of view, the migration rate was low, and the radiological parameters were restored overall. Kutzner et al. [13], who investigated114 Optimys™ stems, also reported an average increase in the overall offset of 2.1 mm, with no clinical impact. They described the different implantation options available based on the preoperative plan. In patients with valgus, making the cut lower on the femoral neck allows the stem to be positioned in valgus when using a highly filling stem. Conversely, in case of varus, the patient's anatomy can be restored by minimizing the neck cut with the option of using a lateralized stem (Figure 4). According to Schmidutz et al. [36], it is more difficult to restore the hip parameters after implanting a short stem. By comparing the modular Metha™ short stem (B-Braun, Aesculap, Tuttlingen, Germany) to a conventional monoblock stem, they observed a tendency with the short stem of increasing the offset and lengthening the leg, which they attributed to the high femoral neck cut. We found no leg length discrepancy in our study. As for the osseointegration, the literature reports similar rates between short and standard femoral stems [37].

Our study has a few limitations: 1) This was a retrospective, non-randomized study, with no power calculation and differences in the surgical approach and bearing used with the acetabular cup. However, each group was operated by a single surgeon using a standardized technique. The sample size and follow-up period were sufficient to achieve statistically significant results. 2) Other parameters are susceptible to impact BMD and to bring about a confusion bias such as age, BMI, activity level, preoperative bone stock, neck-shaft angle and femoral anteversion. However, we evaluated many of these variables preoperatively and found them to be comparable between groups. Also, the absence of overall BMD change in the contralateral hip between 1 and 4 years postoperative suggests that the periprosthetic bone remodeling seen on the operated side was closely linked to the THA procedure. 3) Preoperative BMD would have been a better comparator than the contralateral hip's BMD. However, our patients were comparable in their CTI between the operated and healthy contralateral leg. Also, our study findings are in agreement with those of Martini et al. [38], who showed an increase in the periprosthetic BMD after THA relative to preoperative levels. Lastly, recent studies showing that advanced osteoarthritis is correlated with a reduction in BMD, not an increase, which helps validate our findings [39,40].

5. Conclusion

The medium-term results of short stems are very promising, both in terms of periprosthetic BMD and radiological and clinical results. The stem's design appears to affect bone remodeling. The design of the Optimys^{TM} stem is better a limiting stress-shielding relative to the design of the Vitae^{TM} stem, which is no longer manufactured. Lastly, our results suggest that bone remodeling continues for at least 1 year after the THA procedure.

Study registration ID RCB: 2018-A02507-48

Conflict of interest:

Patrice Mertl is a consultant for DePuy, Stryker and receives royalties from Xnov and Adler, unrelated to this study. Antoine Gabrion has received royalties from Xnov. The other authors have no conflict of interest to declare.

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Author contributions

AD wrote the article, analyzed data and revised the article. KEY collected, analyzed and interpreted the data and wrote the article. PM designed the study. BEF collected and analyzed the data MD interpreted the data and wrote the article AG designed the study, wrote the study protocol and revised the article.

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Table 1: Patient demographics

	Group 1 Vitae™	*Group 2 Optimys™*	*p*
Number of patients	46	47	–
Mean age (years)	66.4 ± 4.8 [52-74]	66.8 ± 6.4 [54-77]	0.111
BMI (kg/m²)	26.1 ± 2.7 [19-31]	26 ± 3.2 [20-32.7]	0.653
Sex ratio (M/F)	22/24	22/25	0.228
Preoperative HHS (/100)	57.5 ± 5.6 [48-68]	58.7 ± 4.8 [47-69]	0.224
HHS at 1 year (/100)	95.3 ± 4.8 [76-99]	95.2 ± 2.6 [88-99]	0.855
Preoperative CTI	0.57 ± 0.06 [0.43-0.71]	0.60 ± 0.06 [0.50-0.74]	0.099
Preoperative femoral offset (mm)	46.4 ± 7.9 [31-65]	46.4 ± 5.5 [35-56]	0.853
Preoperative neck-shaft angle (°)	128.5 ± 6.7 [113-140]	131.8 ± 5.8 [123-145]	0.083
Postoperative neck-shaft angle (°)	130.5 ± 4.7 [122-139]	129.2 ± 6.1 [118-143]	0.455
Postoperative LLD (mm)	−0.4 ± 1.4 [−4.6-2]	−0.3 ± 1.6 [−3.7-3.1]	0.849

(BMI: body mass index, M: male, F: female, HHS: Harris Hip Score [10], *CTI: Cortical Thickness Index, LLD: leg length discrepancy)*

Table 2: Comparison of mean bone mineral density at 1 and 4 years postoperative in the various Gruen zones [11] for the Vitae™ stem group, expressed as a percentage change

	Mean BMD at 1 year	*Std Dev*	*Mean BMD at 4 years*	*Std Dev*	*Percent change*	*p*
Zone 1	0.75	0.17	0.73	0.18	−2%	0.13
Zone 2	1.07	0.32	1.03	0.31	−4.8%	**0.038**
Zone 3	1.54	0.22	1.54	0.22	0%	0.85
Zone 4	1.56	0.29	1.57	0.29	1.6%	0.30
Zone 5	1.67	0.31	1.65	0.32	−1.8%	0.37
Zone 6	1.23	0.34	1.12	0.35	−11%	**0.009**
Zone 7	0.95	0.32	0.89	0.31	−5.8%	**0.003**
Overall BMD	1.2	0.20	1.18	0.20	−1.9%	0.1
Contralateral BMD	0.9	0.14	0.91	0.14	1%	0.1

Table 3: Comparison of mean bone mineral density at 1 and 4 years postoperative in the various Gruen zones [11] for the Optimys™ stem group, expressed as a percentage change

	Mean BMD at 1 year	*Std Dev*	*Mean BMD at 4 years*	*Std Dev*	*Percent change*	*p*
Zone 1	0.69	0.13	0.7	0.13	0.3%	0.75
Zone 2	1.16	0.23	1.03	0.33	−13.7%	**0.018**
Zone 3	1.56	0.22	1.49	0.2	−6%	0.06
Zone 4	1.64	0.28	1.61	0.23	−2.80%	0.72
Zone 5	1.65	0.19	1.65	0.22	−0.5%	0.78
Zone 6	1.32	0.29	1.35	0.31	3%	0.37
Zone 7	1.14	0.23	1.14	0.22	−0.1%	0.96
Overall BMD	1.17	0.14	1.17	0.16	0%	0.1
Contralateral BMD	0.93	0.12	0.93	0.12	0%	0.5

Table 4: Comparison of the mean bone mineral density between groups at 1 and 4 years postoperative

	Vitae stem	Optimys stem	*p*	Vitae stem	Optimys stem	*p*
zone 1	0.75	0.69	0.21	0.73	0.7	0.47
zone 2	1.07	1.16	0.25	1.02	1.02	0.98
zone 3	1.54	1.56	0.75	1.54	1.49	0.46
zone 4	1.56	1.64	0.31	1.58	1.61	0.63
zone 5	1.67	1.65	0.85	1.65	1.65	0.99
zone 6	1.23	1.32	0.27	1.12	1.35	**0.011**
zone 7	0.95	1.15	**0.014**	0.89	1.14	**0.001**
Overall BMD	1.21	1.17	0.45	1.19	1.17	0.72
Contralateral BMD	0.9	0.93	0.4	0.9	0.93	0.52
	Between group comparison at 1 year			**Between group comparison at 4 years**		

Table 5: Radiological and clinical outcomes of short stems in relevant published studies

Author	**Level of evidence**	**Implant**	***n***	**Follow-up (years)**	**Age (years)**	**BMI (kg/m^2)**	**HHS (/100)**	**No. of migrations**	**BMD**
Chen et al. [22]	IV	Mayo™	29	5.7	50.8	nd	nd	nd	↓ zones 1. 6 and 7
Lerch et al. [26]	**II**	Metha™	25	2	58.9	24.6	94	0	↓ zone 1 ↑ zones 3 and 6
Zeh et al. [27]	IV	Nanos™	25	1	59.9	nd	nd	0	↓ zones 1. 2 and 7 ↑ zone 6
Gasbarra et al. [30]	III	Fitmore™	33	1	62.3	23.8	96	0	↑ zones 1 and 7
Brinkmann et al. [23]	II	Metha™ Nanos™	24 26	1	58.7 59.7	27.4 27.1	96.2 96.5	0	↓ zones 1. 6 ↓ zone 1
Synder et al. [29]	IV	Metha™	36	1	50.4	nd	94.1	0	↓ zones 1 and 7
Shafy et al. [31]	II	Mini Hip™	26	2	42.5	27.3	95.1	nd	↑ zones 2.3.4 and 5
Freitag et al. [32]	II	Fitmore™ CLS™	57 81	1	56.8 59.1	29.7 28.3	85 87	0 0	↓ zone 6 CLS > Fitmore
Parchi et al. [28]	III	Metha™	20	4	nd	nd	nd	nd	↑ zones 2.3.5 and 6
Hochreiter et al. [20]	III	Optimys™	46	2	65.7	nd	97.2	nd	↑ zones 2. 3 and 5
Current study	III	Vitae™ Optimys™	46 47	4.2	66.4 66.8	26.1 26.0	95.3 95.2	4 2	↓ zones 2. 6 and 7 ↓ zone 2

(BMI: body mass index, HHS: Harris Hip Score [10]*, BMD: bone mineral density, nd: no data)*

Figure legends

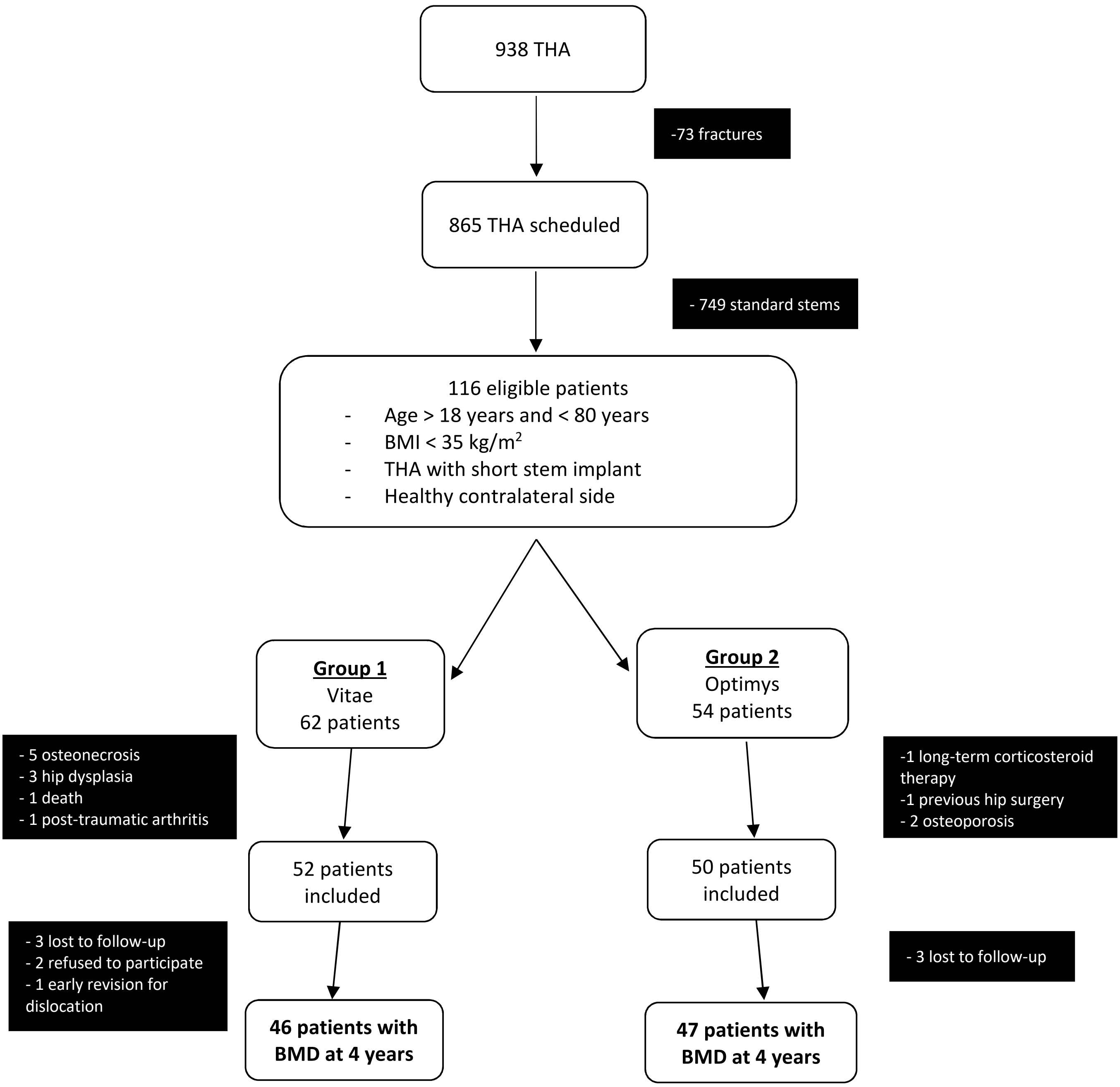
Figure 1: Flow diagram summarizing the study design (BMD: Bone Mineral Density).

Figure 2: Gruen zones [11] adjusted for short stems, (A) Optimys™, (B) Vitae™

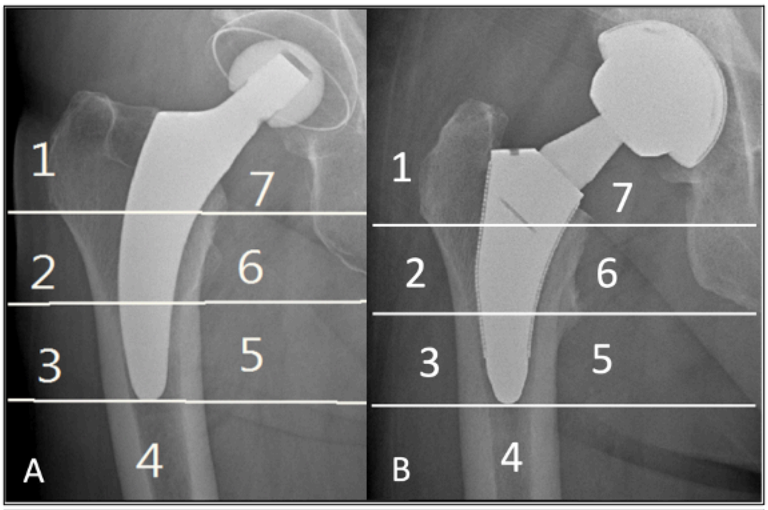
Figure 3: Method used to measure the femoral offset (center of rotation of head–diaphyseal axis), acetabular offset (pelvis axis – head center of rotation) and overall offset (femoral + acetabular) pre- and postoperatively according to Kutzner et al. [13]

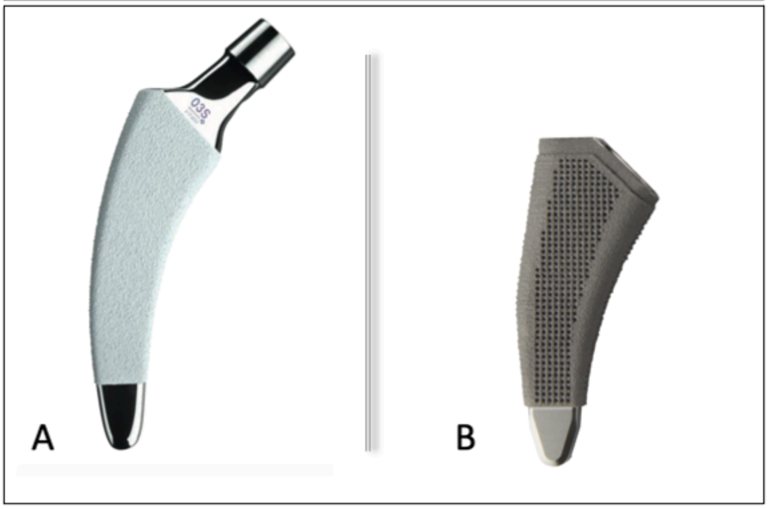
Figure 4: Different options for implanting short stems (A), preoperative valgus with a Optimys™ implant positioned in valgus to restore the offset, (b) preoperative varus with a stem positioned in varus to restore the offset.

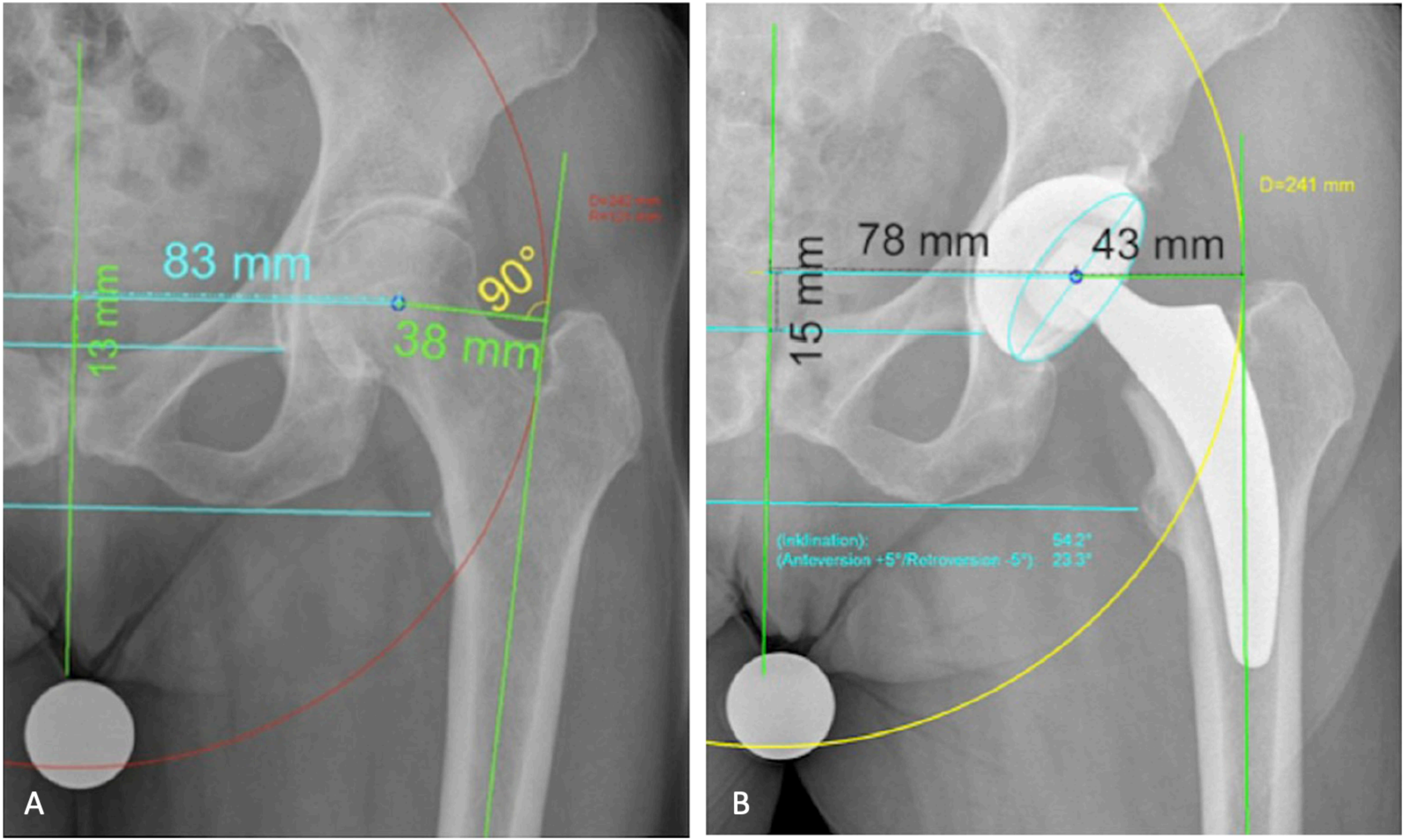
Figure 1:

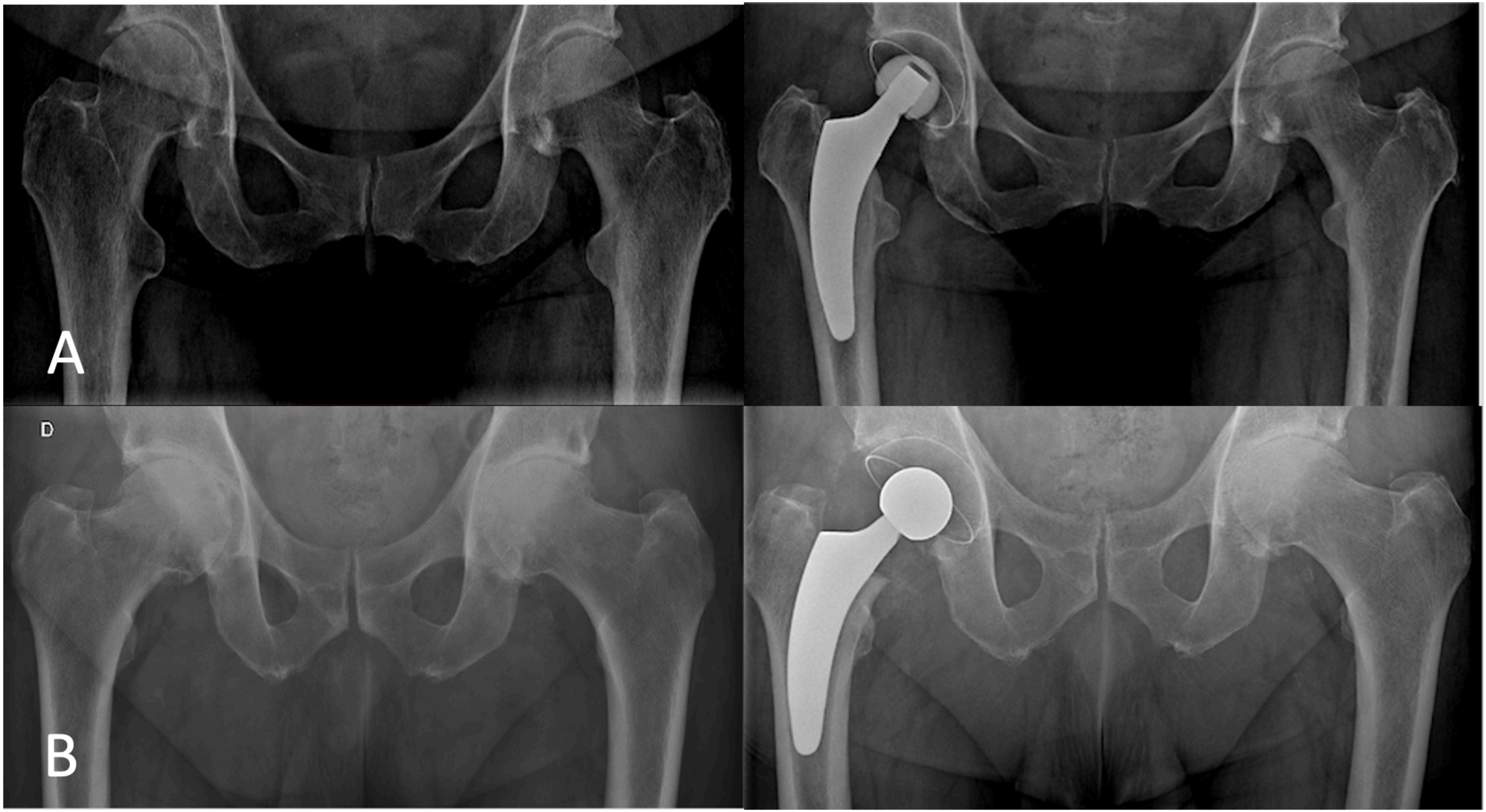


938 THA
-73 fractures
865 THA scheduled
- 749 standard stems
116 eligible patients
- Age > 18 years and < 80 years
- BMI < 35 kg/m^2
- THA with short stem implant
- Healthy contralateral side
Group 1
Vitae
62 patients
Group 2
Optimys
54 patients
- 5 osteonecrosis
- 3 hip dysplasia
- 1 death
- 1 post-traumatic arthritis
-1 long-term corticosteroid therapy
-1 previous hip surgery
- 2 osteoporosis
52 patients included
50 patients included
- 3 lost to follow-up
- 2 refused to participate
- 1 early revision for dislocation
- 3 lost to follow-up
46 patients with BMD at 4 years
47 patients with BMD at 4 years


1
7
2
6
3
5
4
A
1
7
2
6
3
5
4
B


A
B


83 mm
13 mm
38 mm
90°
A
78 mm
43 mm
15 mm
D=241 mm
(Inklination): 54.2°
(Anteversion +5°/Retroversion -5°): 23.3°
B


A
B