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CT-based quantification of bone stock in large head metal-on-metal unilateral total hip replacements

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ABSTRACT

Purpose: To explore ipsilateral and contralateral acetabular roof bone stock density in unilateral large head MoM THA whether there is a significant lower acetabular bone stock in the hip with a metal-on-metal (MoM) total hip replacement compared to the contralateral side. Second part of this study is to examine if there are any associates with regard to potential bone stock density difference.

Materials & methods: A database of 317 patients with unilateral metal-on-metal (MoM) total hip replacements was set up retrospectively for this study. On computed tomography scans, conducted after a relative short in situ time period averaging 2.8 years, regions-of-interests were drawn in the trabecular bone of the acetabulum to measure average Hounsfield Units (HU). HU differences were calculated and tested by Wilcoxon signed-rank test. Univariate analysis was conducted to examine associates of potential bone loss.

Results: In a population of 317 patients (156 male, 161 female) with an average age of 61.9 ± 7.8, the median HU on the side of the MoM replacement was 123.3 (7.6–375.4). On the contralateral side, median HU was 144.7 (−0.4 to 332.8). The median HU difference was 21.4 after a mean post-operative in situ time of 2.8 years. The Wilcoxon signed-rank test proved a significant difference ($p < 0.001$). Univariate analyses show that the in situ time of the MoM THA has a significant correlation with the bone density difference.

Conclusion: Results show a significant lower bone density at the acetabular roof at the side of the prosthesis compared with the contralateral side after short in situ time of the MoM THA in patients with unilateral MoM total hip replacements. In our patient population, the in situ time showed a significant association with the acetabular bone density difference. As acetabular roof bone stock measurements are feasible and show temporal decline this could become an important parameter to be used in orthopedic decision making for revision surgery.

1. Introduction

Metal-on-metal (MoM) total hip replacement was introduced to reduce the complication of wear, increase stability and increase of range of motion as observed in conventional total hip replacement [1]. However concerns about the MoM prostheses increased over time. The MoM prostheses show tissue reactions, including bone loss and formation of pseudotumors in surrounding soft tissues [2–4]. An inflammatory environment as seen in MOM total hip arthroplasty (MoM THA) may predispose to acetabular bone

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loss. Insufficient acetabular bone stock in general may lead to aseptic loosening of the cup and therefore revision surgery [5,6]. More importantly, current MoM screening populations have been associated with high revision rates [7]. Pre-operative assessment of bone stock is of interest when considering and planning revision surgery in MoM patients. Furthermore the quantification of the bone density in the acetabulum might contribute to a better understanding of the biological behavior and failure of total hip replacements in general.

The conventional method to quantify bone mineral density (BMD) is with the use of dual-energy X-ray absorptiometry (DXA) [8]. The BMD is the amount of bone matter per square centimeter (mg/cm^2). It is the most common predictor and indicator of osteoporosis [8]. Recent research however shows that assessment of bone stock by quantification of Hounsfield Units (HU) from the trabecular area obtained with diagnostic computed tomography (CT) scans have a strong, positive correlation with the DXA determined Bone Mineral Density (BMD) [9,10]. This indicates that HU values can be used to examine bone density from diagnostic non iodine contrast CT scans [11]. In general, CT assessment needs calibration for inter-patient analysis. Inter-patient analysis is not yet feasible due to lack of a clinical reference list regarding attenuation of bone in an age and sex adjusted score analog to the T- and Z-score in DEXA [11]. However, it should be possible to detect a bone stock difference between the ipsilateral side of the prosthesis and the contralateral side as differences are not influenced by inter patient CT related differences. A well-known phenomenon is that MoM hip prostheses cause metal streak-artifacts on the CT scan. However, the area superior to the prosthesis is not affected by metal artifacts [11]. For this reason the acetabular roof is the region of interest in this study.

The purpose of this study is twofold. First, to explore ipsilateral and contralateral acetabular roof bone stock density in unilateral large head MoM THA. Second, to examine if there are any associates with regard to potential bone stock density difference.

2. Materials and methods

2.1. Patients & database design

A database with unilateral MoM hip prostheses was extracted from a larger database of 506 THA MoM patients in the period 2010 and 2011 for this study, consisting of all patients with MoM hip prostheses in our institute [12]. 189 patients were excluded due to contralateral THA or patients of which the CT dataset did not match the image criteria (CT datasets had to encompass one centimeter cranial to the top of the MoM prosthesis). All included unilateral MoM THA patients underwent CT scans after implantation. This finally resulted in a study database of 317 patients (156 male, 161 female). All hip replacements were composed of a Bi-Metric porous coated uncemented stem with a metal-on-metal M2a-Magnum femoral head and ReCap acetabular component (Biomet, Warsaw, Indiana, USA). To determine MoM associated hip capsule reaction, patients were graded according to the simplified classification of Boomsma et al. [7] and included in the database.

2.2. Image acquisition

All CT datasets were obtained with the Philips Brilliance 40CT scanner or the Philips Brilliance 64CT scanner. (Philips Medical Systems, Best, The Netherlands) CT parameters included a slice thickness of 0.9 mm, a tube voltage of 140 kV$_p$, mean current of 175 mA (min. 97, max. 347) and a matrix size of 512 × 512 for all reviewed CT datasets. The field-of-view (FOV) of the CT datasets had to encompass one centimeter cranial to the top of the MoM prosthesis. An example is shown in Fig. 1.

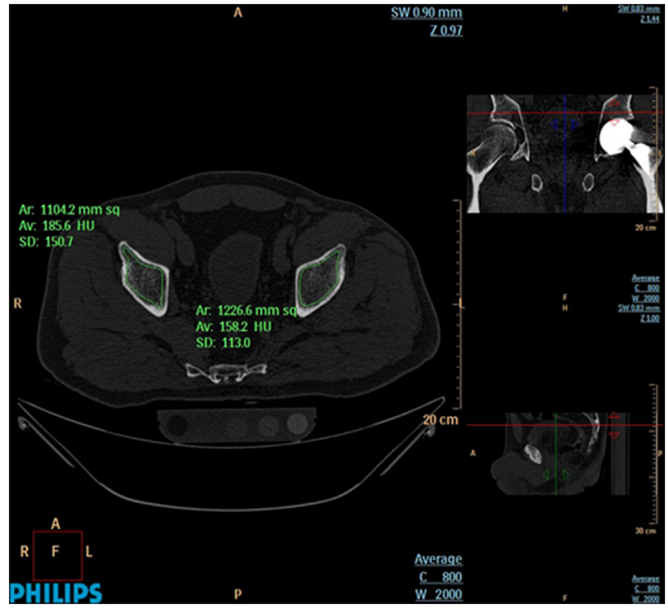

Fig. 1. Example of a HU measurement. ROIs are placed in the trabecular bone at both sides in the acetabular roof region one centimeter above the metal implant. Average HU values are calculated.

2.3. HU measurements

HU analysis was performed in the Philips Extended Brilliance Workspace. CT datasets were analyzed in the CT viewer review module. The slice one centimeter above the metal acetabular implant (cup) was selected for HU measurements. At this level, as expected from literature, metal artifacts from the prosthesis are not present in the longitudinal axis. Therefore, we expect that measured HU values in this region are not influenced by these artifacts. To be sure that one cm is far enough, we have shown in a previous publication that metal artifacts are not present in this region [11]. In the axial plane, regions-of-interest were always placed in the trabecular bone of the acetabular roof, one centimeter above the acetabular roof. The exact placement was determined by coronal assessment and balancing the image in order to be sure that on both sides one centimeter space was left between the acetabular roof and the measurement plane as shown in Fig. 1. Because of the high metabolism in trabecular bone, it is more prone to bone degeneration. For this reason, the cortical bone is not included in the region-of-interest (ROI). For all measurements, the largest possible ROI was drawn, excluding the cortical bone. For both ROIs, the average HU value was calculated. The HU difference was defined as the average HU value at the contralateral side minus the average HU value at the side of the prosthesis. Thus, when bone stock density in the acetabular roof is lower at the ipsilateral side, the HU difference will obtain a positive value.

2.4. Reproducibility

Intra-observer reproducibility of the HU measurements was performed on 50 randomly selected patients from the total patient cohort. Measurements as described above were repeated by the same observer. Slice selection and previous results were not visible to the observer.

Table 1
HU difference values for the different pseudotumor gradation groups.

	Group A	Group B	Group C
N	170	31	116
Median of HU difference	19.1	2.0	24.9
Std. deviation	37.8	63.8	32.1
Minimum	−190.3	−154.7	−82.7
Maximum	189.8	91.4	87.3

2.5. Statistical analysis

All statistical analyses were performed in IBM SPSS Statistics, version 22. To test whether the HU difference for all patients is normally distributed, skewness and kurtosis were calculated. Wilcoxon signed-rank test was used to test HU values at the side of the prosthesis and the contralateral side.

Reproducibility was tested with the intra-class correlation coefficient (ICC) to determine the conformity between the two measurements. The ICC was reported as a score between 0 (no correlation) and 1 (total correlation).

To study the influence of pseudotumor formation on the acetabular bone stock, mean HU differences were calculated for each pseudotumor gradation group. To test if there is a significant difference between group A, B and C capsular reactions [7]. The Mann–Whitney test was performed. Associations with bone stock difference were studied by means of correlation analysis. Only when linearity between the bone stock difference and the potential predictor was observed, univariate linear regression was performed. In this study, patient age, gender, in situ time, pseudotumor gradation, cobalt and chromium levels, inclination, cup size and anteversion were examined. These factors are mainly thought to associate with THA failure in MoM related capsular disease [7].

3. Results

The database of 317 patients (156 male, 161 female) with an average age of 61.9 ± 7.8 was analyzed. The in situ time period between the hip replacement and CT scan (follow-up time) varied from 6 months to 5.4 years. Mean in situ time of the prosthesis is 2.8 years. Mean age of the reviewed patients at time of the CT image acquisition was 61.9 years ±7.8 (29–76).

3.1. Ipsilateral and contralateral HU values

Median HU at the side of the prosthesis was 123.3 with a minimum of 7.6 and a maximal value of 375.4. At the contralateral side, median HU was 144.7 with a minimum of −0.4 and a maximal value of 332.8. The intra-class correlation coefficient of the reproducibility is 0.921 with a 95% confidence interval of [0.866–0.955].

3.2. HU difference

Of all patients, 248 patients have a lower HU value at the side of the prosthesis, 68 patients have a higher HU value and for 1 patient the average HU values were equal both sides. The median of the HU difference was 21.4 HU with a minimum of −190.3 and a maximum of 189.80. Skewness and kurtosis were −0.96 and 5.07 respectively. The normality tests showed a skewed distribution (Shapiro–Wilk showed $p < 0.001$). The Wilcoxon signed-rank test showed that there is a significant difference between the average HU value at the side of the prosthesis and the contralateral side ($Z = -9.142$, $p < 0.001$). Medians for the HU values for the individual pseudotumor gradation groups are listed in Table 1. The Mann–Whitney test showed no significant difference between group A and group C.

Table 2
Linearity analyses.

	Pearson's correlation coefficient	*P*-value
Patient age	−0.083	0.143
Gender	0.034	0.544
In situ time	0.125	0.013
Pseudotumor gradation	0.024	0.666
Cobalt level	−0.065	0.248
Chromium level	−0.067	0.238
Inclination	−0.074	0.188
Cup size	−0.001	0.991
Anteversion	0.024	0.674

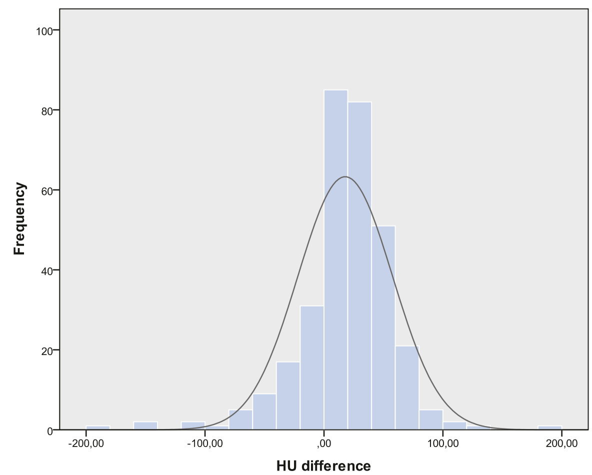

Fig. 2. Histogram of the average HU difference between the acetabular roof at the side of the MoM prosthesis and the contralateral side.

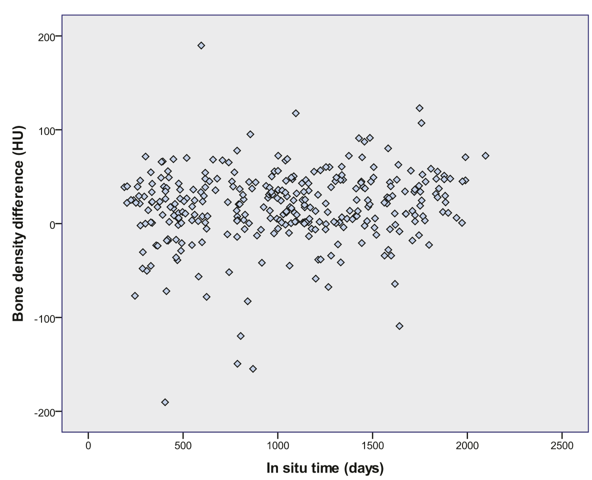

Fig. 3. Scatterplot of in situ time and bone density difference to evaluate linearity.

3.3. Associates of HU difference

The results of the linearity between potential bone loss predictors and the bone stock difference are shown in Table 2. Except for the in situ time, none of the potential predictors showed a significant correlation with the bone density difference. The scatterplot of the in situ time versus the bone density difference is shown in Fig. 3.

Because the in situ time shows a significant correlation with the bone density difference, a linear regression analysis with this variable was performed. The regression coefficient B was 0.011 with a confidence interval of [0.002–0.020]. The *p*-value was 0.013.

4. Discussion

In this study we performed CT-based HU measurements in a large homogeneous cohort of large head MoM THA patients with short in situ time (mean 2.8 years). The results show a relative small but, due to the large number of patients, significant bone density difference of 21.4 HU (range −190.3 to 189.8) between the acetabulum at the side of the prosthesis and the contralateral. The in situ time appeared to be the only linear predicting factor for the bone stock difference. To the best of our knowledge, the use of CT-based HU measurements in the acetabular roof in patients with total hip replacements has not been previously published.

The results replicate findings in which DEXA was used to estimate bone stock in conventional THA [13,14]. Being able to use this non-invasive method offers new possibilities in assessing bone stock in a MoM screening population without additional examinations as is the case with DEXA scans and can be used in follow-up. If screening of MoM patients for capsular disease with CT is performed, BMD measurements can be obtained together with measurements of rotation and anteversion of the femoral stem and measurements of anteversion and inclination of the cup [15]. These measurements add information for the orthopedic surgeon who considers and plans potential revision. Measurements as performed in this study can be implemented on all non-iodine contrast CT scans. In this study, the average HU is used to represent acetabular bone density. Recent research shows a significant correlation between the HU measured by CT and the BMD measured by DXA [10]. Schreiber et al. and Lee et al. [9,10] correlated Hounsfield Units in the vertebrae with T-scores. Respectively, they found a T-score of ≥ -1 (normal) correlated to a HU of 133 and 121, a T-score between −1.0 and −2.5 (osteopenic) correlated to a HU of 101 and 79 and T ≤ -2.5 (osteoporotic) correlated to a HU of 79 and 55.

The use of the average HU also has its limitations. Hounsfield Units depend on a number of factors, including patient constitution, radiation dose and scanning artifacts. Consequently, comparison between patients is not possible at this moment. In order to make bone-density comparisons between patients and relate it to BMD measurements from DXA scans, the bone mineral density should be calculated. This could be done in a phantom-less method in which internal references from fat and muscle are used. Because no phantom-less BMD analysis software suitable for measurements in the hip is yet available, at this point in time average Hounsfield Units were used [11].

An important limitation in this study is the absence of a baseline CT measurement before implementation of the total hip replacement as primary pre-operative planning consists of conventional radiographs and therefore no CT data are available. In the future new full iterative reconstruction techniques will decrease dose dramatically and CT scans might be more routinely performed pre-operatively as more information can be obtained by means of CT than with conventional radiography. Due to the lack of baseline measurement pre-operatively we cannot state that the absolute bone loss is only due to the intrinsic characteristics of the MoM prosthesis.

Inflammatory conditions in a joint is known for bone loss in general. Therefore it could be expected that the inflammatory environment as seen in a large percentage of MoM THA patients might attribute to bone loss. As we did not find a correlation between the grade of the capsular reaction as can be observed in MoM screening populations this seems not to be the case.

The variations in measurements, visible in the histogram in Fig. 2, shows a relatively wide range of HU differences [−190.3 to 189.8] with a mean of 18.1 HU. This mean is significantly different from zero, however a well-grounded explanation for the wide range cannot be provided with the knowledge obtained from this study.

5. Conclusion

In this study a statistically significant bone density difference with respect to the contralateral side by means of CT analysis between the acetabulum at the side of the prosthesis and the contralateral side after 2.8 years postoperative follow-up in patients with unilateral MoM total hip replacements is shown. Only the in situ time of the MoM THA showed a significant correlation with the bone density difference. Pseudotumor formation did not correlate with bone density differences. As acetabular roof bone stock measurements are feasible and show temporal decline this could become an important parameter to be used in orthopedic decision making for revision surgery.

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