Retroacetabular Stress-shielding in THA

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Abstract We conducted a randomized clinical trial to compare periacetabular bone density changes after total hip arthroplasty using press-fit components with soft and hard liner materials. Bone density changes were assessed using quantitative computed tomography-assisted osteodensitometry. Twenty press-fit cups with alumina ceramic liners and 20 press-fit cups with highly cross-linked polyethylene liners were included; the nonoperated contralateral side was used as the control. Computed tomography scans were performed postoperatively and 1 year after the index operation. At the 1-year followup, we found no differences of periacetabular bone density changes between the alumina and polyethylene liner cohorts. However, we observed marked periacetabular cancellous bone density loss (up to −34%) in both cohorts. In contrast, we observed only moderate cortical bone density changes. The decrease of periacetabular cancellous bone density with retention of cortical bone density after THA suggests stress transfer to the cortical bone.

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Introduction

Periacetabular bone remodeling after total hip arthroplasty (THA) is a complex phenomenon which mainly depends on mechanical properties of the bone, the mode of fixation, implant geometry and stiffness, age, and patient activity level [1, 6, 14]. Loss of acetabular bone density (BD) may compromise the long-term outcome of the implant [2].

Quantitative computed tomography (qCT) osteodensitometry is a relatively new technology used for assessing bone structures with high resolution and reproducibility [8, 10, 16, 17]. In comparison to dual-energy x-ray absorptiometry, qCT is 3-D and allows separate assessment of cortical and cancellous bone [15]. Wright et al. [23] reported a 20% to 33% decrease of BD 1 year after THA using qCT analysis of cancellous bone above the dome of press-fit acetabular components with a polyethylene (PE) liner. Bone density changes were higher in regions closer to the cup dome. They attributed this bone loss to retroacetabular stress-shielding. Mueller et al. [12] subsequently reported periacetabular cancellous BD loss is higher than cortical BD loss in a consecutive cohort of patients undergoing THA with press-fit cups and alumina liners. Acetabular components designed for insertion with ceramic liners need a solid metal shell with high structural stiffness to prevent risk of liner fracture. It is uncertain if the mechanical properties of these constructs influence the stress transfer to the acetabulum and pelvic bone, and subsequently bone remodeling. A finite-element analysis of press-fit cups with alumina liners showed equatorial stress distribution to the acetabulum, and stress-shielding of the pole. In contrast, cups with PE liners showed polar stress distribution and equatorial stress-shielding [4]. However, it is unclear whether stiffness of the cup or the liner or both influence the cancellous (rather than cortical) bone density.

We asked whether liner material influences periacetabular loss of cancellous and cortical BD.

Materials and Methods

We prospectively randomized 50 consecutive patients (50 hips) meeting our criteria to receive either a press-fit cup (Trilogy; Zimmer Inc, Warsaw, IN) with a highly cross-linked PE liner (Longevity; Zimmer) or the same cup with an alumina ceramic liner (BioloX Forte; CeramTec, Plochingen, Germany). Patients presenting with degenerative hip disease for THA management were considered for inclusion in the study. We excluded those with acetabular deformity (dysplasia, protrusio, previous fracture), patients younger than 18 years or older than 80 years, those who refused to consent, were pregnant, previously failed THA, and/or had THA in the contralateral hip. With a two-sided 95% confidence interval, we rated a sample size of 20 hips in each cohort would have 80% power to detect a 5% BD difference between the two implants. We recognize the clinical relevance of a 5% BD loss in the acetabular region after THA remains unknown. At the 1-year followup, 40 of the 50 hips included in the study had preoperative, postoperative, and followup qCT data sets for densitometry analysis. Four patients had incomplete qCT data sets, four patients were lost to followup, and two patients moved overseas. Age, gender, bone stock, and functional level of the patients were similar in the two hip cohorts (Table 1). The study was approved by the local ethics committee. All patients fulfilling the selection criteria accepted to participate. Informed consent was obtained before the surgical procedure.

Table 1. Patient demographics

Variable	Alumina liner	Polyethylene liner
Number of patients	20	20
Gender (women/men)	13/7	12/8
Mean age at index operation	64.5 years (range, 39–79 years)	66.1 years (range, 40–78 years)
Level of activity		
Sedentary	—	—
Semisedentary	1	—
Light labor	11	12
Moderate manual labor	8	7
Heavy manual labor	—	1
Bone stock (Singh rating) [20]		
5 (ward area empty)	2	3
6 (inferior ward area well defined)	13	11
7 (normal)	5	6

An uncemented stem (Versys Fibre Mesh; Zimmer) was used in the patients younger than 60 years, and a cemented stem (Versys Heritage; Zimmer) was used in older patients. A 28-mm alumina ceramic femoral head (BioloX Forte; CeramTec) was used in all hips.

Randomization was performed with use of sealed envelopes containing a slip indicating the allocation, which had been derived from a computer-generated sequence. No restriction was applied to the assignment of the implants. The implant assignment was concealed until the time of surgery. All surgical procedures were performed by one surgeon (RPP) in one institution using a direct lateral approach. The acetabulum was prepared with reamers to obtain a bleeding surface; the surgeon aimed to preserve as much of the subchondral bone structures as possible. In all hips press-fit fixation of the Trilogy cup was obtained with a 2-mm oversizing of the diameter of the implant. Additional dome screw fixation was not used in the two cohorts of patients. Physical therapy, range-of-motion exercises, and walking with partial weight bearing were usually initiated on the second postoperative day. Full weight bearing was started at week 2 postoperatively.

We (AB, SP) evaluated the clinical outcome using the Harris hip score and the Oxford patient questionnaire (performed preoperatively and at 6 weeks and 1 year postoperatively). The clinical assessments were performed by individuals not involved in the treatment.

We took serial anteroposterior and lateral view plain radiographs of the hip preoperatively and at clinical followups. The radiographs were assessed (RP, SP) using the criteria of Johnston et al. [7]. The surgeon was not involved in the assessment of outcomes.

CT scans were performed within the first 10 days after THA and at the 1-year followup. We used a conventional CT scanner (Siemens SomatomPlus, Erlangen, Germany) and a standardized scanning protocol (140 kV, 206 mAs, 150 mm × 150 mm field of view) with 2-mm slice thickness and serial axial scan acquisitions at 10-mm intervals. Three of the six axial scans were performed above the cup; three scans were performed at the level of the cup (Fig. 1). Analysis of the ventral and dorsal regions of the retroacetabular area was performed by dividing the scan images through a coronal line passing across the center of the femoral head. Thus, qCT analysis of cancellous and cortical BD changes at the 1-year followup was carried out on three main acetabular regions of interest (ROIs) (cranial, dorsal, ventral) (AB, SP, JTM). The nonoperated contralateral side was used as the control. An extended CT scale was used to reduce metal artifacts [9]. The CT scans were downloaded onto specialized software (CappapostOP; CAS Innovations, Erlangen, Germany). This software allowed separate analysis of the cortical and cancellous bone structures (Fig. 2). Radiographic BD values (Hounsfield

Fig. 1 The computed tomography scout image shows the axial imaging levels (horizontal lines) around the press-fit cup used for assessment of bone density. Three scans were taken above the dome of the cup. Scan 1 (solid line) was positioned 2 cm above the cup, and scan 3 was positioned tangentially to the most proximal point of the cup.

Fig. 2 The computed tomography image shows the acetabulum with the press-fit cup. The dedicated quantitative computed tomography software allows separate assessment of cortical and cancellous bone around the press-fit cups with minimal metal artifact production. The ventral and dorsal regions of interest are divided by a coronal line crossing the center of the femoral head.

units) were converted into true BD (mgCaHA/mL) using a calibration phantom containing a circular sample of well-defined hydroxyapatite concentration (800 mg CaHA/mL) [8, 9, 16].

The continuous demographic data of the two groups of patients were analyzed with use of a two-tailed, unpaired t-test. For rank-scaled data, median values were given with

the interquartile range. Relative frequencies of unpaired samples were compared with the Fisher's exact test. Unpaired groups of continuous data without assumption of normal distribution were compared with the Mann-Whitney U test. Two-sided p values of ≤ 0.05 were considered significant. We corrected for multiple comparisons using the Hommel method to control Type I error. Calculations were carried out using SPSS for Windows (version 9; SPSS, Chicago, IL).

Results

At the 1-year followup, we found no difference in clinical and radiographic outcome between the two patient cohorts. The mean preoperative Harris hip score of the 40 hips was 42 points (range, 38–62 points); 1 year after the index operation the mean score was 92 points (range, 80–96 points). At the 1-year followup, there were no clinical or radiographic signs of aseptic loosening. No hip had undergone revision surgery.

We found no difference in periacetabular BD changes between the two patient cohorts. Changes of cortical BD were moderate in both cohorts (Fig. 3). In some scans BD increased, while in other scans we observed a BD decrease (range, -12% to $+14\%$). Cancellous BD loss was higher ($p \leq 0.005$) than cortical BD loss in all scans (range, 55–121 mg CaHA/mL) (Fig. 4). The remarkable loss of cancellous BD (up to -34%) was observed in both cup liner cohorts. Cancellous BD loss was higher ($p \leq 0.005$) in scans closer to the cup (range, 206.7–306.1 mg CaHA/mL). We observed no changes in cortical and cancellous BD at the 1-year followup around the control nonoperated site.

Fig. 3A–C Percent change in cortical bone density (A) cranially, (B) ventrally, and (C) dorsally to the cup 1 year after the index operation of two cohorts of hips with highly cross-linked polyethylene or alumina liners (scans 1 to 3 are above the cup; scans 4 to 6 are at the same level of the cup).

Discussion

THA influences both periacetabular cortical and cancellous bone density. However, it is unclear whether stiffness of the cup or the liner or both influence the cancellous (rather than cortical) bone density. We therefore asked whether liners of different materials influence periacetabular loss of BD after THA.

Our study had some limitations. The short followup does not allow determination of whether these BD changes are reversible or permanent. Periacetabular BD changes could be a result of surgical trauma or midterm bone remodeling processes after press-fit fixation of the cup. However, a previous qCT osteodensitometry study suggests progressive cancellous BD loss even 3 years after THA in a consecutive cohort of press-fit cups with alumina liners [13]. Osteodensitometry assessment could not be blinded for the line type because alumina and PE liners can easily be recognized on the CT scans. However, we do not believe lack of blinding influenced our assessment of periacetabular BD changes.

Fig. 4A–C Percent change in cancellous bone density (A) cranially, (B) ventrally, and (C) dorsally to the cup 1 year after the index operation of two cohorts of hips with highly cross-linked polyethylene or alumina liners (scans 1 to 3 are above the cup; scans 4 to 6 are at the same level of the cup).

Using an axisymmetric finite element model to investigate stress distribution pattern after cemented THA Pedersen et al. [14] reported reduced stresses in the cancellous bone in the region medial and superior to the acetabulum. This was associated with a reduction of stress level in the medial pelvic cortical bone while lateral cortex loading increased. Huiskes [5] investigated with finite element the load transfer mechanism and stress patterns in the acetabulum reconstructed with an uncemented threaded cup and also found the cup behaves as a relatively rigid implant shielding the cancellous bone and enhancing load transfer to the cortical bone. Other studies of finite element models and computer simulation programs for strain-adaptive bone remodeling after THA suggest flexible materials and press-fit fixation reduces stress-shielding [19, 21]. However, they also reduce the potential for interface stability. To date, there are no data supporting the hypothesis that the liner material influences the stiffness of a press-fit cup. Moreover, there is no evidence supporting the assumption that mechanical properties of liners may affect periacetabular bone remodeling processes after press-fit cup fixation. In a matched-pair study with a minimum 5-year followup, Schmidt et al. [18] found no

difference in clinical and radiographic outcomes between two cohorts of hips managed with press-fit cups inserted with alumina or PE liners.

Recently, Moore et al. [11] described a method to radiographically determine osseointegration of an uncemented, porous-coated acetabular component. Four of the five criteria (presence of a superolateral buttress; medial stress-shielding; radial trabeculae; an inferomedial buttress) are radiographic signs of marked bone remodeling processes showing rarefaction of the periacetabular cancellous bone. Radiographic changes of bone structures around orthopaedic implants are detectable on plain radiographs only after a loss of BD of up to 70% [3]. Thus, more sensitive and specific methods are necessary to assess bone density changes around a THA. Wilkinson et al. [22] assessed retroacetabular BD with dual-energy xray absorptiometry 13 months after the index operation of 17 THAs with uncemented cups and found changes in three of four ROIs. However, he reported problems identifying the threshold between bone and implant in cases with strong cortical bone. Digas et al. [2] assessed acetabular BD with dual-energy xray absorptiometry in three cohorts of patients with press-fit cups or cemented cups using two different types of bone cement. The authors reported that, after 2 years, loss of periprosthetic BD in the region of interest above the cup increased with higher postoperative BD and when the uncemented design had been used. Wright et al. [23] reported a 20% to 33% decrease of BD in the ilium region 1 year after THA with a press-fit cup and PE liner. Bone density was assessed within a specific ROI that was defined by a cylinder of cancellous bone centered within the ilium directly above the dome of the acetabular component. The distance between the five sections was 2.5 mm, and the cross-sectional area of the cylinder was 100 mm [2]. In our study, the qCT equipment allowed assessment of the whole cross-section of the acetabulum, including the cortical bone. In a previous consecutive series of 26 press-fit cups with ceramic liner assessed with qCT 1 year after THA, we observed marked signs of cancellous bone stress shielding. Density of cancellous bone decreased 35% in the retroacetabular pubis region, 30% in the ischium region, and 18% in the ilium region. In contrast, cortical BD decreased 6% and 4% in the pubis and ischium regions, respectively, and increased 4% in the ilium region [12].

We found no difference of periacetabular BD changes in the two cohorts of cups with soft and hard liner materials. The decrease of periacetabular cancellous bone density after THA suggests stress transfer to the cortical bone. Increased loss of BD with use of press-fit cups in the region in which osteolysis is commonly found suggests stress-shielding may facilitate the formation of periacetabular lytic changes. We suspect a compromised cancellous bone structure in the periacetabular region plays an important

role in the propagation and expansion of lytic changes, although we have no data to support this contention. Further basic science and clinical research will be necessary to substantiate this hypothesis.

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