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Prospective bone density changes after periacetabular osteotomy: a methodological study

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Abstract We used computed tomography (CT) and 3D design-based sampling principles (stereology) to estimate changes in acetabular bone density after periacetabular osteotomy. We included six consecutive patients with hip dysplasia in the study. Baseline density was measured within the first 7 days following periacetabular osteotomy and compared with bone density 2 years later. Double measurements were performed on three patients, and the coefficient of error of the mean was estimated to 0.05. Bone density in zone 1 increased significantly in the anteromedial quadrant as well as in the posteromedial quadrant of the acetabulum. In the anterolateral and the posterolateral quadrant, bone density was unchanged. In zone 2 and 3, bone density was unchanged 2 years postoperatively. We suggest that the observed increase in bone density medially represents a remodelling response to an altered load distribution after osteotomy. The method used is a precise tool to estimate changes in acetabular bone density.

Résumé Nous avons utilisé la tomodensitométrie et les principes de l'échantillonnage sur dessin en 3D (stéréologie) pour estimer les changements de la densité osseuse

acétabulaire après ostéotomie périacétabulaire. Nous avons inclus consécutivement six malades avec une dysplasie de la hanche. La densité de référence a été mesurée dans les sept jours suivant l'ostéotomie périacétabulaire et a été comparé avec la densité de l'os deux ans plus tard. Des doubles mesures ont été exécutées sur trois malades et le coefficient d'erreur moyen a été estimé à 0,05. La densité de l'os en zone 1 est augmentée notablement dans le quadrant antérointerne ainsi que dans le quadrant postérointerne de l'acetabulum. Dans les quadrants antéroexterne et postéroexterne la densité était inchangée. Dans les zones 2 et 3 la densité osseuse était inchangée deux ans après l'opération. Nous suggérons que l'augmentation observée de la densité de l'os interne représente une réponse de remodelage à une modification de la distribution de la charge après l'ostéotomie. La méthode utilisée est un outil précis pour estimer les changements dans la densité de l'os acétabulaire.

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Introduction

The cause of osteoarthritis in hip dysplasia is thought to be attributable to increased joint contact pressures secondary to decreased acetabular coverage of the femoral head and/or incongruity of the articular surfaces [10]. Early degenerative changes in the articular cartilage of the hip joint are accompanied or preceded by increased subchondral bone density, leading to the sclerosis observed radiographically [3].

Periacetabular osteotomy is a joint-preserving surgical treatment of hip dysplasia (Fig. 1), the goal of which is to increase acetabular coverage of the femoral head in order to prevent or postpone the natural history of osteoarthritis [13]. The osteotomy results in an increased acetabular load-bearing area [9] and improved load distribution over the available cartilage surface. Postoperatively, load on the lateral part of the acetabulum is decreased and load on the medial part is increased. Consequently, a relevant issue is whether this change in load distribution will affect acetabular bone density over time in a way that bone density

Fig. 1 X-ray before and after periacetabular osteotomy. **a** Preoperatively, approximately 50% of the femoral head was uncovered by the acetabulum. **b** X-ray 6 months after periacetabular osteotomy fixed with two long titanium screws. The femoral head was now covered by the acetabulum. Note that the pubic, ischium, and ilium osteotomy was solidly healed after 6 months.

will increase in areas with more load and decrease in areas with less load.

Stereological methods are used to obtain quantitative information about three-dimensional structures based on observations from section planes. Such methods can be used with computed tomography (CT) images to collect quantitative prospective bone-remodelling data. The present study describes a method based on CT and 3D design-based sampling techniques by which bone density in different regions of the acetabulum can be estimated.

Patients and methods

The study was approved by the local ethical committee. After signed consent, six patients (five women and one man) with hip dysplasia, scheduled for a periacetabular osteotomy were consecutively included in the study. Their mean age was 33 (26–39) years. The indication for operation was hip dysplasia with a center-edge angle of Wiberg smaller than 25° and osteoarthritis grade 0, I, or II according to the classification of Tönnis [15]. The pubic, ischial, and ilium cuts were performed as described by Ganz et al. [5]. The amount of 3D reorientation of the

acetabular fragment was based on preoperative CT measurements (center-edge angle, acetabular sector angles, and the anteversion angles of the femoral neck and the acetabulum) as described by Anda et al. [1]. All operations were performed by the same surgeon (KS). All patients had spherical femoral heads. Three patients had grade II osteoarthritis, and three had no osteoarthritis. Patients younger than 20 years and patients with dysplasia caused by neurological conditions, Legg–Calvé–Perthes' disease, or previous surgery of the hip were excluded from the study. Patients in whom a femoral osteotomy was indicated were also excluded.

CT (Marconi M $\times$ 8,000) scanning of the pelvis and distal femur was done postoperatively and 2 years after surgery. Spiral multislice 4×2.5 mm (3.2 mm effective slice thickness) CT sections, increment 1.6 mm, were performed with a pitch of 0.875 (120 kV, 150 mAs, field of view 400 mm, standard algorithm). The patients were positioned supine on the scanning table with a 4-cm pillow between the knees and both legs in neutral rotation.

The CT scanner was calibrated against air on a weekly basis and against water four times a year. Every 6 months, a test was made for CT-number linearity utilizing Philips Medical System Phantome. Scan data were transferred to a Marconi Mx View workstation and reconstructed. The CT images of the hip joint were reformatted in order to view them as sagittal slices through the joint. The images were viewed and it was noted at which slice the femoral head came into view and at which slice the femoral head disappeared. Slices displaying the femoral head were chosen, and the central slice could be identified. The diameter of the femoral head on the central slice was noted, after which the central point of the femoral head could be determined (Fig. 2). Knowing the central point enabled a division into an anterior and posterior part, and subsequently the acetabulum could be divided into four quadrants. Laterally to the central slice, an anterolateral (al) and posterolateral (pl) quadrant could be defined. Correspondingly, an anteromedial (am) and a posteromedial (pm) quadrant were defined medially to the central slice (Fig. 3).

The objective of dividing the acetabulum into four quadrants was to obtain detailed information of bone density in different acetabular regions using systematic, uniformly

Fig. 2 The x value for the anterior and posterior edge of the femoral head was noted, after which the diameter and the central point (CP) of the femoral head could be determined

Fig. 3 **a** The acetabulum divided into four quadrants illustrated by an axial CT image of the top of the femoral head. **b** A sagittal computed tomography (CT) image showing how the acetabulum is divided into an anterior and posterior part based on the central point. The artifacts are caused by an inserted screw

random sampling. Firstly, the acetabulum was divided into three zones: the closest to the joint, 4 mm, was defined as zone 1, the next 4 mm (from 4 to 8 mm) was defined as zone 2, and the next 12 mm (from 8 to 20 mm) was defined as zone 3. Secondly, a point-counting grid with squares of 4×4 mm was placed on each CT image. Thirdly, when a point in the counting grid hit one of the zones in the acetabulum, CT values were registered (points in cysts, osteophytes, and screw were excluded). In this way, CT values of the three zones on all sagittal images were collected, and a mean CT value for the three zones in four quadrants was estimated postoperatively and 2 years after surgery. A data set of about 500 measurements for each acetabulum was collected at each time interval.

The precision of this method in quantifying bone density of the acetabulum was determined by the accuracy the operators in registering CT values at the crosses in the grid. We estimated the precision of the method by performing double measurements of the same scan data by the same operator on three patients and studied whether the time taken by this method could be reduced by registering the CT value in every second or third cross in the grid.

Statistics

Data was analyzed in SPSS 10.0. The measurements from the first postoperative week were compared with measurements 2 years postoperatively using a paired *t* test. After double measurements, the coefficient of error of the mean was estimated for bone density in the three acetabular zones [6, 11].

Results

Two years after the periacetabular osteotomy, bone density in zone 1 in the anteromedial quadrants had increased from mean CT of 673 [0.14] (506–764) {[coefficient of variation (CV)] (min–max)} to a mean of 716 [0.11] (577–792), $2p=0.025$. Density in the posteromedial quadrants increased from a mean CT value of 643 [0.18] (476–784) to a mean of 709 [0.19] (526–896), $2p=0.006$.

In zone 1 of the anterolateral quadrants, bone density was unchanged with a mean CT value of 748 [0.10] (649–854) following the operation and a mean of 718 [0.16] (565–894), $2p=0.394$ 2 years later. The same was true for the posterolateral quadrants where bone density had an initial CT value of 812 [0.12] (683–975), and 2 years later it was 789 [0.14] (687–957), $2p=0.472$ (Fig. 4).

None of the changes in bone density in zones 2 and 3, 2 years after the periacetabular osteotomy, were statistically significant (Table 1).

This method to estimate bone density took approximately 5 h to carry out per hip. After double measurements of the bone density were performed, the coefficient of error of the mean was estimated to be 0.05. The coefficient of error of the mean was 0.06 and 0.07 on the basis of registering the CT value at every second or third cross in the grid.

Discussion

Our study showed that bone density in zone 1 increased significantly in the medial quadrants. If the six patients were analysed in two subgroups (with or without preoperative osteoarthritis), the bone density in both lateral quadrants decreased in three patients. However, these changes were not statistically significant. Yet an increase in density medially and a decrease laterally is consistent with how the load is distributed after a periacetabular osteotomy. The (nonsignificant) decrease in the lateral quadrants substantiates the assertion that subchondral sclerosis can be reversed.

In two patients, bone density decreased in three quadrants, and in one patient, it increased in all quadrants. This finding suggests that 2 years postoperatively, subchondral sclerosis had increased and osteoarthritis progressed. Common for these three patients was that they all had grade II osteoarthritis preoperatively whereas the other three pa-

Fig. 4 Bone density in zone 1 of the medial and lateral quadrants of the acetabulum just after periacetabular osteotomy and 2 years postoperative. The three patients with a preoperative degree II osteoar-

thritis are marked with a *black dot*, and the three patients with no preoperative osteoarthritis are represented with a *white dot*.

Table 1 Computed tomography (CT) values in zone 2 and 3 in four quadrants at the time of operation and 2 years postoperatively

Zone 2				Zone 3			
Quadrant	CT value at operation, mean [CV] (min-max)	CT value 2 years postop, mean [CV] (min-max)	2p	CT value at operation, mean [CV] (min-max)	CT value 2 years postop, mean [CV] (min-max)	2p	
Anteromedial	508 [0.18] (362-591)	524 [0.13] (410-624)	0.509	363 [0.26] (221-460)	424 [0.24] (267-580)	0.056	
Posteromedial	453 [0.23] (314-609)	471 [0.25] (287-610)	0.490	310 [0.26] (237-413)	317 [0.31] (236-482)	0.651	
Anterolateral	631 [0.16] (514-765)	590 [0.22] (415-729)	0.371	425 [0.18] (321-543)	462 [0.24] (290-588)	0.132	
Posterolateral	650 [0.13] (582-794)	685 [0.29] (472-982)	0.637	409 [0.12] (317-457)	653 [0.40] (401-1,009)	0.090	

tients had no osteoarthritis. Bone density in zone 2 and 3 increased for all quadrants except one; however, none of the changes were statistically significant. The results for zone 2 and 3 indicate that bone density in the acetabulum 8–20 mm proximal to the joint is unchanged 2 years after a periacetabular osteotomy.

When periacetabular osteotomy is performed, the hip joint is corrected and preserved. By collecting prospective bone-remodelling data, we wanted to study how this affected bone density. Schmidt et al. [12] studied bone remodelling 1 year after total hip arthroplasty based on CT. At the acetabular level, one axial scan was performed, and bone density immediately proximal to the press-fit acetabular component was decreased while cortical bone density was increased. This finding suggests an altered stress pattern within the pelvis resulting from implantation of the cup. This is in accordance with Wright et al. [16] who found that acetabular bone-mineral density decreased significantly 1.28 years after total hip arthroplasty for treatment of advanced osteoarthritis. The decreased bone density seen in these studies is probably an effect of stress shielding. This is not to be expected after a periacetabular osteotomy, as no implantation has taken place. Trumble et al. [14] reviewed the results of 123 periacetabular osteotomies at an average follow-up of 4.3 years. Based on an evaluation of anteroposterior (AP) pelvic radiographs, they found increased subchondral sclerosis in 99 hips preoperatively and in only 15 hips at the latest follow-up.

The CT values for zone 2 and 3 show that bone density gradually increases the closer to the joint the CT value shows, most likely because the bone is exposed to a higher load close to the joint. The results for all three zones also showed that the observed total variance [coefficient of variation (CV)] on acetabular bone density is relatively small. The CV includes the biological variation, $CV(\text{bio})$, and the variation due to the applied method [coefficient of error of the mean (CE)]. The following relationship exists: $CV^2 = CV^2(\text{bio}) + CE^2$. Normally, a study is designed so that $CE^2/CV^2 \sim 0.2\text{--}0.5$, as the CE will then only have a limited influence on the total variation (CV). In this study, $CE^2/CV^2 = 0.13$ when all test points were used, $CE^2/CV^2 = 0.19$ when every second test point was used, and $CE^2/CV^2 = 0.25$ when every third test point was used. Changes in acetabular bone density can be estimated by the described method, which is unbiased and precise. If bone density is estimated by registering CT values on every second or third cross in the grid, time can be reduced to about 2–3 h per hip. Based on the above-mentioned considerations, we suggest only using every third test point.

The hypothesis is that with the dysplastic oblique acetabular roof that incompletely covers the femoral head, weight-bearing forces are concentrated over a smaller area than normal [8]. This mechanical situation equates to an increase in the force per unit area and results in abnormally high levels of stress and strain. This study demonstrates that when the force per unit area is changed permanently, subchondral bone (zone 1) is remodelled to adapt to these changes by increasing bone density medially to withstand

the higher load postoperatively and may show (in three patients) that bone density laterally is decreased as a result of reduced load in the lateral part of the acetabulum. Wolff's law has been the basis for the adaptive bone-remodelling theories [7]. These theories assume a relationship between a local mechanical stimulus and the bone-remodelling rate.

In the past three decades, research into the aetiology of osteoarthritis has been concentrated on the articular cartilage destruction where damage is clearly visible. Osteoarthritis develops and changes very slowly, making it difficult to follow over any length of time. The pathological changes occur in all elements of the joint, and cartilage surface disruption is a constant finding [4]. Recent investigations have proved that subchondral bone may be involved and plays a significant role in the cartilage degeneration of osteoarthritis [2]. Subchondral bone sclerosis may not be required for initiation of cartilage fibrillation but may be necessary for progression of osteoarthritis [2].

Owing to the strict inclusion criteria for participating in this study, the findings for the six patients are not due to hip dysplasia caused by other conditions. Consequently, the data material is optimal for assessing the effect of periacetabular osteotomy on acetabular bone density. More patients have to be followed over a longer period of time to assess the clinical implications of these findings, as the group of six patients is too small and heterogeneous to reveal clear evidence of prospective changes in bone density. It is difficult to obtain permission from the ethical committee to CT scan patients more times for research purposes only, and we did not want to include patients younger than 20 years of age. The present study indicates that the described method is a precise tool to estimate bone density changes in the acetabulum.

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