

# Changes in load-bearing area after Ganz periacetabular osteotomy evaluated by multislice CT scanning and stereology

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**Background** We used a stereologic method based on 3D CT scanning to estimate the projected load-bearing surface in the hip joint.

**Patients and methods** 6 normal hip joints and 6 dysplastic hips were examined. The latter were CT-scanned before and after periacetabular osteotomy.

**Results** We found that the average area of the projected load-bearing surface of the femoral head preoperatively was 7.4 (6.5–8.4) cm<sup>2</sup> and postoperatively 11 (9.8–14) cm<sup>2</sup>, which was similar to the load-bearing surface in the normal control group. We performed double measurements and the coefficient of error of the mean was estimated at 1.6%. Due to overprojection, an overestimation of about 3.8% on the projected load-bearing surface occurred. Consequently, the stereologic method proved to be precise and unbiased.

**Interpretation** Our findings indicate that this method is of value for monitoring the load-bearing area in the hip joint of patients undergoing periacetabular osteotomy.

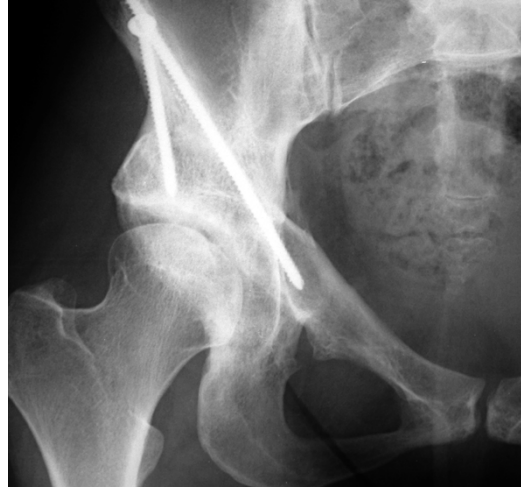
A study has shown that arthrosis is caused by hip dysplasia in nearly half of the hips requiring treatment (Aronson 1986). It is believed that hip dysplasia increases the joint contact pressures that cause degenerative changes and secondary arthrosis (Ganz et al. 1988). Early surgical treatment of hip dysplasia that preserves the joint is thought to prevent or defer the natural history of arthrosis (Søballe 2001).

The aim of periacetabular osteotomy is to recreate a relatively normal shape and anatomy of the joint. This procedure may increase the projected load-bearing surface of the femoral head, reduce joint contact pressures and improve the load distribution over the available cartilage surface (Figure 1).

Hip dysplasia can be diagnosed on plain radiographs, however, plain films lack 3-dimensional information on the degree and location of dysplasia (Janzen et al. 1998). Poor acetabular coverage of the femoral head is a problem not only laterally but as much anteriorly and posteriorly. Mathematical estimates of acetabular coverage have been made from plain radiographs but the methods are complex and require several assumptions regarding the geometry of the hip joint (Haddad et al. 2000). Methods based on CT have also been described. Anda et al. (1991) reported a CT method for determining acetabular coverage by use of the acetabular sector angles. Janzen et al. (1998) used a 3-dimensional CT method to measure acetabular coverage. Recently, stereologic methods have been developed to obtain quantitative information about 3-dimensional structures on the basis of observations from section planes or to a limited degree projections (Nyengaard 1999). We describe a method based on CT and stereology, in which the area of the projected load-bearing surface of the femoral head can be estimated.



Figure 1. Patient 4. Preoperatively radiograph. About 50% of the femoral head was uncovered by the acetabulum. The center-edge angle was  $-10^\circ$ .



6 months after periacetabular osteotomy fixed with 2 long titanium screws. The femoral head was now covered by the acetabulum and the center-edge angle was  $21^\circ$ . Note that the pubic, ischium and ilium osteotomies were well healed after 6 months.

## Patients and methods

The study was accepted by the local ethics committee. Patients less than 20 years of age and those in whom the dysplasia might have been affected by neurological illnesses, Legg-Calvé-Perthes disease or sequelae after previous hip surgery were excluded as also were patients who required an intertrochanteric femoral osteotomy. After signed consent, 6 patients (5 females) with hip dysplasia scheduled for periacetabular osteotomy were consecutively included in the study. Their mean age was 33 (26–39) years. All 6 patients had spherical femoral heads. The indication for surgery was hip dysplasia with a center-edge angle of Wiberg less than  $25^\circ$  and arthrosis degree 0, 1 or 2 with the Tönnis classification (1984). The pubic, ischial and ilium cut incisions were made as described by Ganz et al. (1988). The amount of 3D reorientation of the acetabular fragment was based on CT measurements (center-edge angle, acetabular sector angles and the anteversion angles of the femoral neck and the acetabulum) made as described by Anda et al. (1991). All operations were performed by the same surgeon (KS). Pelvis (both hip joints) and distal femur were CT scanned before and after the periacetabular osteotomy to compare the load-bearing surface pre- and postoperatively. The CT scans were done using a Marconi Mx8000 mul-

tislice scanner. The patients were placed supine on the scanning table with a 4 cm pillow between the knees and both legs in neutral rotation. Spiral multislice  $4 \times 2.5$  (3.2) mm 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). This method of estimating the projected load-bearing surface took about 45 minutes to perform on each hip.

The scan data were transferred to a Marconi Mx View workstation and reconstructed. Then the CT images of the hip joint were reformatted to view them as sagittal slices through the joint. A system of co-ordinates with an x-axis and a y-axis provided exact information on the position of the cursor on the reformatted CT images. The images were examined (Figure 2) and it was noted at which slice the femoral head came into view and at which slice the femoral head disappeared whereupon the number of slices showing the femoral head was determined and the central slice could be identified. The x-value (in the system of co-ordinates) for the anterior and posterior edges of the femoral head on the central slice was noted, after which the diameter and the central point of the femoral head could be determined (Figure 3a). We then defined the central point of the femoral head at this exact position with an exact x-value for all images. On the following sagittal slices

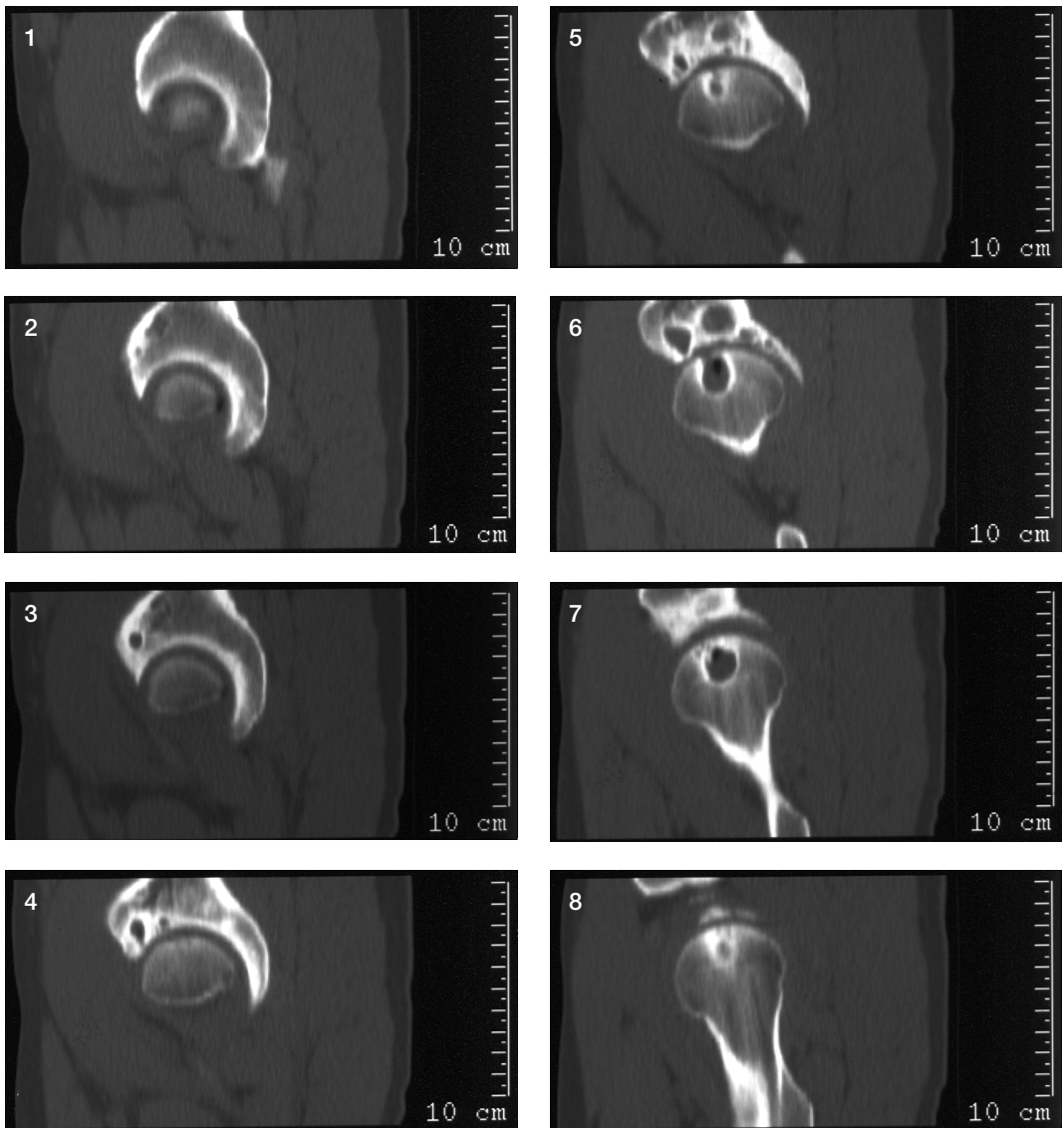


Figure 2 (1–8). Every other sagittal reformatted CT image through the hip joint in patient 3 before surgery.

we noted, the x-value for the projected acetabular margin on the femoral head anteriorly and posteriorly and measured the horizontal distance to these two points (Figure 3). These distances were added, half the maximum diameter of the femoral head subtracted and multiplied by the thickness of the section. In this way the distances contributed to the load-bearing area divided into 4 quadrants. Laterally to the central slice, an anterolateral (al) and a posterolateral (pl) quadrant were defined. Similarly, an anteromedial (am) and a posterome-

dial (pm) quadrant were defined medially to the central slice (Figure 4).

The area of a quadrant (am) was estimated by this equation:

$$A(\text{am}) = (\sum \Delta(\text{am}) - \frac{1}{2} D)t$$

A = area,  $\Delta = l \times (\text{anterior}) - x (\text{central point})$ , D = maximum diameter and t = section thickness.

The area of the projected load-bearing surface was divided into four quadrants to obtain detailed information about the acetabular coverage of the femoral head.

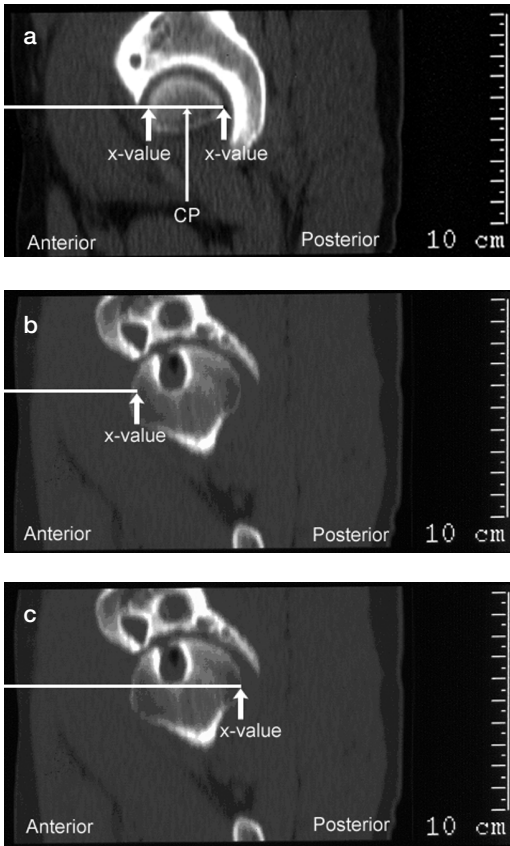


Figure 3. CT image of the central slice (a) and a more lateral slice (b and c) in patient 3.

- The x-value for the anterior and posterior edges of the femoral head were noted after which the diameter and the central point (CP) of the femoral head were determined.
- Distance measured to the anterior projected acetabular margin on the femoral head.
- Distance measured to the posterior projected acetabular margin on the femoral head.

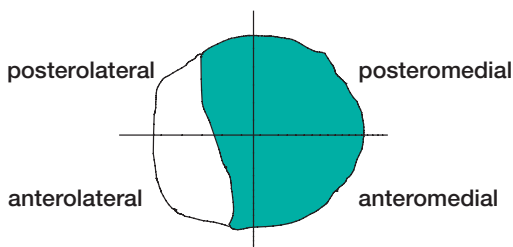


Figure 4. The projected load-bearing surface (dark area) of the femoral head in patient 2 is projected here onto a 2-dimensional horizontal plane to illustrate the 4 quadrants.

We obtained normal values for the projected load-bearing surface from 6 control persons (4 females) without hip dysplasia. Their mean age was 52 (27–77) years. They were older than the patients with hip dysplasia. The mean radius of the femoral head was 2.2 cm in both groups. The control persons had an acetabular or pelvic fracture requiring CT scanning. We used the acquired CT data from the normal hip joints in this study to compare the load-bearing surface of the patients and the control persons.

The validity of this method was determined by the ability of the CT scanner to represent the scanned area with the correct dimensions on the CT images. Overprojection results from positive section thickness of transparent slices, which makes all measurements of nontransparent structures larger. The best way to avoid overprojection bias is to make section planes as thin as possible (Nyengaard 1999). To determine whether the estimation of the load-bearing surface, based on multislice CT, is affected by overprojection, we scanned an object of measurable dimensions. The scan parameters were identical to those used in the patients.

The precision of this method in estimating the load-bearing surface was determined by how accurately the measurer could measure the diameter on the central slice and the distances to the projected acetabular margin anteriorly and posteriorly on the femoral head. We estimated the precision of the load-bearing surface, by performing double measurements on 2 patients, and studied whether the time taken by this method could be reduced by estimating the area of the projected load-bearing surface on every other sagittal reformatted CT image.

### Statistics

The data were evaluated for normality. The area of the projected load-bearing surface of the patients before and after surgery were compared with the paired t-test. The area of the projected load-bearing surface of the patients after surgery and that of the control persons were compared with the unpaired t-test. The correlation between the center-edge angle and the area of the projected load-bearing surface was analyzed with Pearson's correlation coefficient. After double measurements the coefficient of error of the mean was estimated for the

## The projected load-bearing surface and center-edge angles before and after surgery and in the control persons

Patient	Gender	Age (years)	CE <sup>a</sup> angle		Load-bearing surface		Control persons	Gender	Age (years)	CE <sup>a</sup> angle (°)	Load-bearing surface (cm <sup>2</sup> )
			preop. (°)	postop. (°)	preop. (cm <sup>2</sup> )	postop. (cm <sup>2</sup> )					
1	F	39	-1	25	7.1	11.2	1	F	50	33	12.6
2	F	32	9	33	7.4	10	2	M	77	31	13.4
3	M	33	-6	12	8.4	14.3	3	F	51	29	10.6
4	F	26	-10	21	6.5	10.3	4	F	55	33	10.5
5	F	30	7	14	7.2	9.8	5	F	54	30	11.2
6	F	39	-6	27	7.9	10.7	6	M	27	34	12.6

<sup>a</sup> CE Center-edge

total area of the projected load-bearing surface (Gundersen et al. 1999, Nyengaard 1999).

## Results

After periacetabular osteotomy, the area increased by a mean of 49 (35–70)%,  $p < 0.001$  (Table). The correlation coefficient between the correction achieved for the center-edge angle and the increase in the projected load-bearing surface after periacetabular osteotomy was  $r = 0.51$  ( $p = 0.3$ ).

The average area of the projected load-bearing surface of the femoral head before surgery (7.4 cm<sup>2</sup>) was significantly smaller than that after surgery (11 cm<sup>2</sup>) and significantly smaller than the average of the normal hip joints 11.8 (10.5–13.4) cm<sup>2</sup>. The average area of the projected load-bearing surface of dysplastic hip joints postoperatively was similar to that of the normal control group. This was also true for the quadrants, apart from the area of the posterolateral quadrant which was smaller ( $p = 0.001$ ) than the same area in the control group (Figure 5).

After making the double measurements of the total load-bearing surface, the coefficient of error of the mean was estimated at 1.6%. The coefficient of error of the mean was 2.8% on the basis of every other CT slice of the load-bearing surface.

An overestimation of about 3.8% on the projected load-bearing surface occurred due to over-projection when the estimate was based on 2.5 mm CT images. In our opinion, this error was too small to be clinically relevant.

## Loadbearing area (mm<sup>2</sup>) after PAO

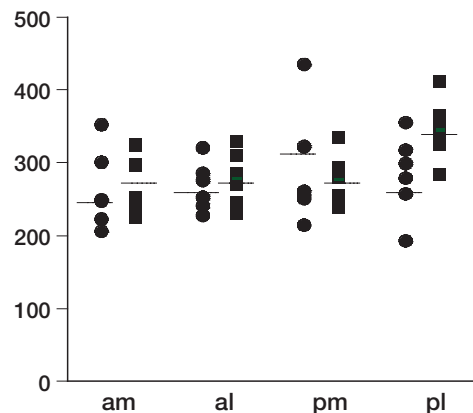


Figure 5. Each patient is indicated by a dot postoperatively and each control person by a square. The group mean of the area of the quadrants is shown by a bar.

## Discussion

The aim of periacetabular osteotomy is to increase the load-bearing area in the hip joint and it is therefore relevant to question whether this area had increased postoperatively. To answer this question, we estimated the area of the projected load-bearing surface. In our patients, the projected load-bearing surface had increased by an average of 49% postoperatively. The correlation between the center-edge angle postoperatively and the increase in the projected load-bearing area was not statistically significant, perhaps because of the small number of patients; larger studies are needed to determine whether such a correlation exists. The effect of

periacetabular osteotomy on the load-bearing surface can be evaluated by our method, which is simple to learn and easy to perform. It is unbiased and based on double measurements, its precision is high. Moreover, if the estimated projected load-bearing surface is based on every other instead of every sagittal reformatted CT image, the time can be reduced to about 25 minutes for each hip without sacrificing high precision.

The age and gender of the patients and of controls varied. However, the mean radius of the femoral head was 2.2 cm in both groups, which justifies comparing the area of the projected load-bearing surface of the normal hip joints with the dysplastic hip joints postoperatively.

Hip dysplasia means that an oblique acetabular roof covers the femoral head insufficiently, which results in a smaller articulating surface between the femoral head and the acetabulum and increases contact pressures. Pressure can be thought of as the stress generated over a surface by a distributed force (Lucas et al. 1999). To minimize contact pressures, the distributed forces must be reduced or the part of the articular surface transferring the forces must be increased. The area of the projected load-bearing surface is directly related to the level of contact pressure and, consequently, contact pressures in these 6 patients was reduced after periacetabular osteotomy.

Some studies show that contact pressures in dysplastic hip joints are higher than in normal hips (Hipp et al. 1999, Pomme et al. 2000). We found that the average area of the projected load-bearing surface postoperatively (11 cm<sup>2</sup>) was close to that of the projected load-bearing surface in normal hips (11.8 cm<sup>2</sup>). Theoretically, this means that contact pressures in dysplastic hip joints postoperatively are similar to those in normal hip joints. However, there is no proof that a reduction in contact pressure on cartilage will slow or prevent additional degeneration of the joint. Moreover, irreparable damage to the cartilage may have occurred at the time of the periacetabular osteotomy in these patients. Therefore, it can not be concluded that the degenerative changes in the hip joint have stopped or decreased after periacetabular osteotomy.

The area of the posterolateral quadrant in the group of dysplastic hip joints was smaller than

that in the group of normal hips. This finding supports the views of Haddad et al. (2000) who found that when performing a periacetabular osteotomy, posterior cover is less adequately dealt with. It is uncertain whether this is of clinical importance. The contact stress in the human hip is not uniform and it changes with changes in body position. The variations in location of the peak contact stress during gait may indicate the sites of predilection for further development of arthrosis in the hip joint. On the basis of laboratory measurements and by using mathematical models of forces and stresses in the human hip, Mavcic et al. (2000) determined the points of the peak contact stress in successive phases of gait. They found that such stress is mostly located in the posteromedial quadrant of the load-bearing area. In dysplastic hips, it is located more laterally and anteriorly. However, the location of this stress was studied during gait only, but when the patients rise from a chair, climb stairs and do other daily activities, the peak contact stress may be located elsewhere.

Owing to the strict inclusion criteria for participation in this study, the findings in the 6 patients are not due to hip dysplasia caused by other illnesses. Consequently, they are optimal for assessing the effect of periacetabular osteotomy on the projected load-bearing surface of dysplastic hip joints.

Our data indicate that this method precisely monitors the load-bearing area of the hip joint in patients undergoing periacetabular osteotomy. It may be of value for learning more about the degree of reorientation of the acetabulum and its relation to clinical outcome after periacetabular osteotomy.

No competing interests declared.

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