

Outcome of periacetabular osteotomy

Joint contact pressure calculation using standing AP radiographs, 12 patients followed for average 2 years

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Background Due to wide variations in acetabular structure of individuals with hip dysplasia, the measurement of the acetabular orientation may not be sufficient to predict the joint loading and pressure distribution across the joint. Addition of mechanical analysis to preoperative planning, therefore, has the potential to improve the clinical outcome.

We analyzed the effect of periacetabular osteotomy on hip dysplasia using computer-aided simulation of joint contact pressure on regular AP radiographs. The results were compared with the results of surgery based on realignment of acetabular angles to the normal hip.

Patients and methods We studied 12 consecutive periacetabular osteotomies with no femoral head deformity. The median age of patients, all females, was 35 (20–50) years. The median follow-up was 2 years (1.3–2.2). Patient outcome was measured with the total score of a self-administered questionnaire (q-score) and with the Harris hip score. The pre- and postoperative orientation of the acetabulum was defined using reconstructed 3D CT-slices to measure angles in the three anatomical planes. Peak contact pressure, weight-bearing area, and the centroid of the contact pressure distribution (CP-ratio) were calculated.

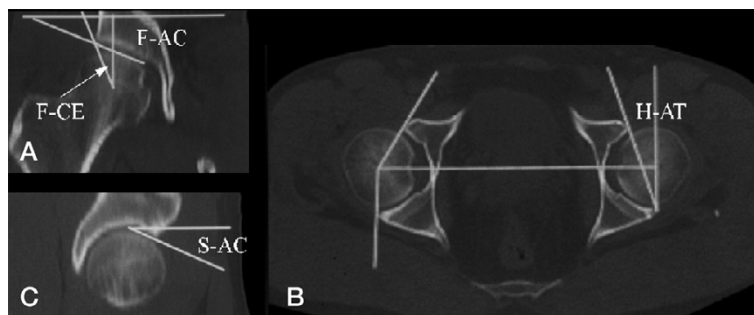
Results While 9 of 12 cases showed decreased peak pressure after surgery, the mean changes in weight-bearing area and peak contact pressure were not statistically significant. However, CP-ratio changed ($p < 0.001$, paired t-test) with surgery. For the optimal range of CP-ratio (within its mid-range 40–60%), the mechanical outcome improved significantly.

Interpretation Verifying the correlation between the optimal CP-ratio and the outcome of the surgery requires additional studies on more patients. Moreover, the anatomically measured angles were not correlated with the ranges of CP-ratio, suggesting that they do not always associate with objective mechanical goals of realignment osteotomy. Mechanical analysis, therefore, can be a valuable tool in assessing two-dimensional radiographs in hip dysplasia. ■

AP radiographs are the most common imaging technique used for patients with hip dysplasia. While pelvic AP and oblique radiographs are used for preoperative planning before periacetabular osteotomy, the diagnosis and follow-up routines are usually based on AP radiographs showing both hip joints (Sibenrock et al. 1999). The AP views are standardized using a standing (weight-bearing) posture to improve the assessment of joint-space (Turula et al. 1985). Because a pelvic AP view is taken of every patient with dysplasia, independent of the treatment, these views can be used to compare patient outcomes.

Klaue et al. (1988) introduced the use of CT for preoperative planning based on 3D imaging of the pelvis. Our work comparing the alignment between normal and dysplastic joints simplified the practical application of this technique (Lepistö et al. 1998). Presently, our institution which uses this method as a standard surgical planning tool for

Figure 1. Reformatted CT slices: A) frontal view, B) horizontal view, and C) sagittal view. The realignment angles shown in their respective views are as follows. F-AC: articular cartilage angle in the frontal plane; F-CE: center edge angle in the frontal plane; S-AC: articular cartilage angle in the sagittal plane; H-AT: anteversion angle in the horizontal plane. F-AC angle was defined as the angle between



the horizontal line and a line connecting the medial edge of the sourcil line and the most lateral point on the acetabulum (points 4 and 5 in Figure 3), measured clockwise. F-CE angle was defined as the angle between a vertical line passing through the center of the femoral head and a line between the center of the femoral head and the most lateral edge of the acetabulum, measured counterclockwise. S-AC was defined as the angle between a horizontal line and a line passing through the anterior edge of the contact surface, and the upper most point of the acetabular contact surface. H-AT was defined as the angle of a line parallel to the opening of the acetabulum and a line perpendicular to the line drawn through the centers of the femoral heads.

hip dysplasia. Diagnosis and follow-up, however, is still based on AP pelvic radiographs.

Since the structure of dysplastic hips varies markedly, it is difficult to establish general guidelines for surgery. Pelvic osteotomy is performed to relieve pain and avoid joint subluxation by improving the contact pressure distribution and the femoral head coverage. Because the contact pressure distribution following surgery cannot be characterized from the preoperative plan, surgeons typically try to reproduce the joint coverage seen in normal hips. The characteristics of correct alignment for the contact surface have been sought by comparing the contact pressure distribution for the normal and dysplastic hips, both computationally (Genda et al. 1995, Hipp et al. 1999) and experimentally (Michaeli et al. 1997). Previous studies have lacked information about the influence of anatomical variations between patients on the contact pressure distribution, however. In order to evaluate how effectively pelvic osteotomy procedures improve the contact pressure distribution in dysplastic hips, we performed a mechanical study of patients treated with a pelvic osteotomy. Our hypothesis was that the radiographically measured parameters used to assess the alignment of the joint surface do not necessarily correlate with the mechanical goals of periacetabular osteotomy.

Methods

The osteotomies were performed between Octo-

ber 26, 1995 and October 16, 1996. The criteria for recommending operative treatment for adult hip dysplasia remained constant in our institution during that time period. Periacetabular osteotomy is the suggested treatment if the patient suffers from constant pain related to the loading of the hip, and if the range of motion allows correction without remarkable compromise of function. In each case, the surgeon was provided with a standing AP radiograph (Turula et al. 1985) of the pelvis and reformatted CT-slices through the center of the femoral head in frontal, sagittal, and horizontal planes (Lepistö et al. 1998) (Figure 1). 12 consecutive periacetabular cases, excluding patients with a history of femoral head deformation (e.g. Legg-Perthes-Calvé) or with a radiographically detected deformation of the femoral head (e.g. coxa plana), were studied. The median age of the patients, all females, was 35 (20–50) years. The surgeon aimed at correcting multiple angles defining joint alignment (Figure 1) to reproduce values typical of normal joints (Lepistö et al. 1998). The surgeon fixed 2 K-wires to the osteotomized bone fragment and two to adjacent pelvic bone. Measuring angles between these K-wires and using the AP view of an image intensifier, the surgeon could assess the change in acetabular alignment.

Surgical outcomes were determined from the results of a self-administered questionnaire (Johanson et al. 1992) and the (Harris 1969) hip score. An independent orthopedic surgeon carried out the latter assessment. Follow-up period was defined as the period between the operation and the latest

Table 1. Progressive degenerative changes in the hip joint (Tönnis, 1987)

Grade	Radiographic findings in standing AP radiograph
0	No signs of osteoarthritis
1	Increased sclerosis of the head and acetabulum, increasing narrowing of the joint space, slight lipping at the joint margins
2	Small cysts in the head or acetabulum, increasing narrowing of the joint space, moderate loss of sphericity of the head
3	Large cysts in the head or acetabulum, severe narrowing or obliteration of the joint space, severe deformity of the head. Necrosis

clinical examination. The median follow-up time was 2 (1.3–2.2) years.

Postoperative radiographs and CT scans were taken a minimum of 4 months after the surgery using the standardized technique described. An independent radiologist assessed both preoperative and postoperative radiographs in a blinded fashion. Lateral and anterior coverage were measured as changes in frontal AC-angle (F-AC) and CE-angle (F-CE) and sagittal AC-angle (S-AC) in CT-slices (Figure 1). Before the surgery, degeneration of the hip joint was graded from 0 to 3 (Table 1).

The preoperative and postoperative radiographs were digitized and tested in a blinded fashion. The magnitude and orientation of the reaction force of the hip joint was calculated by balancing the abductor muscle forces and moments and the body weight. Preoperatively, the direction of the line of pull of the abductor muscles was set to 21° with respect to a vertical line (Bombelli 1981). Postoperatively, it was corrected based on the change in the angle of pelvis tilt, and lateral/medial or superior/inferior movement of the hip center (Figure 2).

The joint contact pressure was calculated using discrete element analysis (Kawai and Takeuchi 1981, An et al. 1990). This technique modeled a two-dimensional representation of the hip contact surface as a series of linear elastic elements (springs) distributed over the surface area between the femur and the pelvis. The joint reaction force, passing through the center of the head of the femur, was distributed over the surface using the principle of minimum potential energy. If some of the elastic elements on the surface were subjected to a ten-

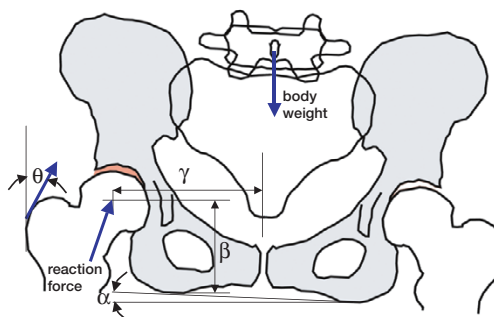
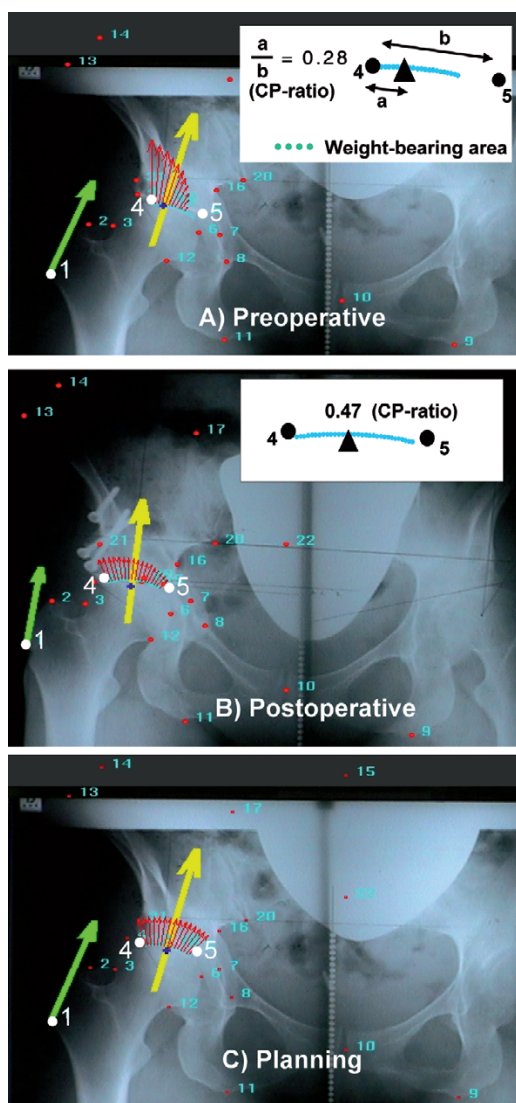


Figure 2. The preoperative abductor angle ($\theta = 21^\circ$) was corrected for the postoperative AP radiographs by considering the change in the angle of pelvis tilt (α), superior/inferior movement of the hip center (β), and the lateral/medial movement of the hip center (γ).

sile force, they were eliminated and the algorithm was reiterated in order to redistribute the contact pressure. Reiterations were repeated until all of the elastic elements were loaded in compression. This technique may result in a weight-bearing area different from the potential contact area defined clinically by the lateral and medial edges of the sourcil line. This can be seen in Figures 3 and 4, where the potential contact area with boundaries at points 4 (lateral edge of acetabulum) and 5 (medial edge of sourcil line) as the initial estimate of the weight bearing area, was different from the final calculated weight-bearing area (the area under the small arrows in Figures 3 and 4). The contact pressure distribution ratio (CP-ratio) was developed to characterize the distribution of pressure along the potential contact area as a single parameter. CP-ratio is defined as the distance from the point at which the centroid of the contact pressure crosses the joint surface to the lateral edge of the potential contact area divided by the total potential contact area (Figure 3). The discrete element analysis technique uses considerably less computational power than finite element analysis while giving a reasonable approximation of the pressure distribution (Li et al. 1997). Because of the computational speed, the technique can be used for interactive preoperative planning of the surgery. Recently, this technique has been evaluated for the calculation of contact pressure distribution in patellofemoral joints (Elias et al. 2004) and hip joints (Armand et al. 2002).

The effect of surgery on the contact pressure distribution was studied by comparing the preopera-



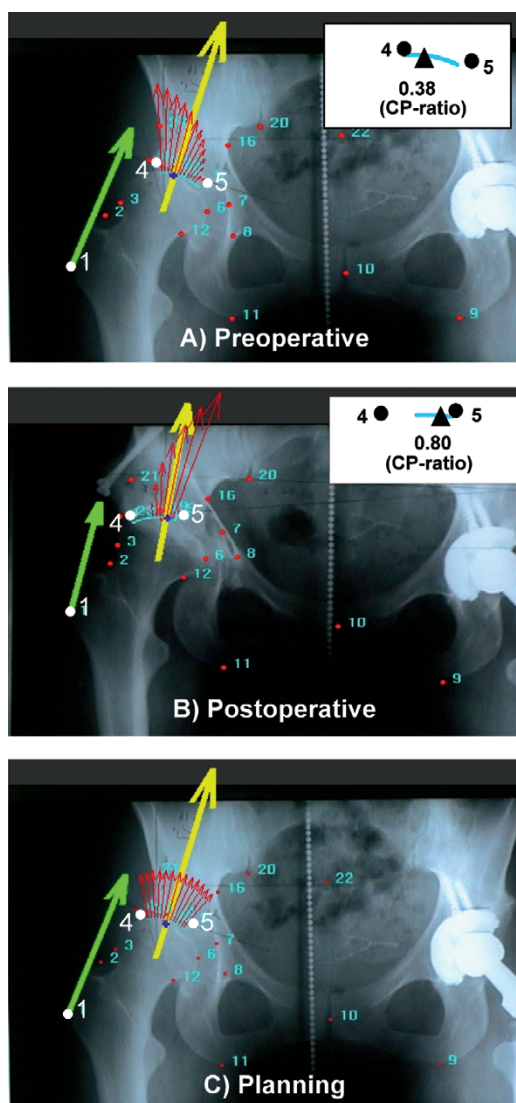
tive situation to that after surgery. The simulated magnitude of peak contact pressure (PP), joint weight-bearing area (WBA), and contact pressure centroid (CP) were used as indices of loading conditions. The potential contact area was defined as the area between the medial and lateral edges of the sourcil line. Prior to the study, a sensitivity analysis was performed by varying the abductor force angle and the osteotomy angle on radiographs with various contact surface areas. This was done to verify that the CP-ratio index is unambiguous and the maximum contact pressure approaches a minimum as the CP approaches the center of

Figure 3. An example of a case with a low pressure gradient. A) This preoperative radiograph shows that the contact pressure distribution (small arrows) does not span the entire potential contact area (defined by the area between the lateral edge (point 4) and medial edge (point 5) of the sourcil). The peak contact pressure is on the lateral edge (point 4). Also shown in the figure are the line of pull of abductor force, with its origin at the most lateral edge of the greater trochanter (point 1), and the joint reaction force passing through the centroid of contact pressure (shown by a "+" sign). The insert shows how CP-ratio and weight-bearing area are defined with respect to the sourcil line. B) The postoperative radiograph shows an even distribution of contact pressure after surgery. Also, the size of the weight-bearing area has approached that of the potential contact area (between points 4 and 5). The peak pressure is not on the lateral edge, and the centroid of contact pressure distribution has moved to the center of the contact area (CP-ratio approached 0.5). Note also that the direction of the abductor force is corrected for pelvis tilt and the medial movement of the femur joint center. C) The preoperative planning based on minimizing the joint contact pressure shows that an acetabular rotation of 10.5 degrees would result in an even distribution of joint contact pressure (mean/peak pressure = 1) over the entire potential contact area. The CP-ratio is 0.5. In this example, optimizing acetabular rotation according to the peak pressure resulted in a situation close to that seen in the postoperative image. However, the surgical procedure produced additional changes in acetabular orientation (e.g. medialization). This obviously further reduced the peak contact pressure. In this example, F-AC angle changed from 18° preoperatively to -2° postoperatively, and the F-CE angle changed from 30° preoperatively to 54° postoperatively.

the contact surface. Based on the above indices, the results were divided into two groups: 1) group A, which included the cases with a postoperative weight-bearing area close to the potential contact area. This group had a CP-ratio within the range of 0.4–0.6, indicating a relatively large weight-bearing area (Figure 3); and 2) group B, which included all other cases (Figure 4).

Mechanical preoperative planning was performed using the preoperative radiographs. Acetabular center of rotation was determined by digitizing several points between medial and lateral edges of the sourcil line and fitting a sphere using the simplex optimization technique (Gill et al.1991). During biomechanical planning, using Brent's optimization algorithm (Brent 1973), the contact surface was rotated around this center until the lowest peak contact pressure value was reached.

In order to evaluate the consistency of the results, two independent investigators digitized anatomical landmarks on the pre- and postoperative radiographs for all 12 patients, as shown in Figures 3 and



4. The algorithm used these landmarks to calculate static loads and contact pressure distributions.

Statistics

Statistical comparisons were used to determine the influence of surgery on mechanical parameters, outcome assessment and acetabular orientation. Differences in these parameters between patients in group A and group B were also characterized statistically. Paired t-tests were used to compare preoperative to postoperative parameters for all 12 patients. A nonparametric Mann-Whitney rank sum test was used to compare data between groups

Figure 4. An example of a case with high pressure gradient. The figures are arranged as in Figure 3. In this example, 8.5° lateral rotation of the acetabulum during biomechanical preoperative planning (C) resulted in an even pressure distribution over the whole potential contact area. However, the postoperative analysis (B) showed significant differences compared to the biomechanical planning results, indicating nonoptimal surgical outcome in terms of joint contact pressure. Postoperatively, we observed a high peak pressure and remarkably smaller weight-bearing area. The CP-ratio was 0.8, and the peak contact pressure was shifted toward the medial edge (point 5). F-AC angle changed from 19° preoperatively to -7° postoperatively, and the F-CE angle changed from 15° preoperatively to 50° postoperatively.

A and B, due to the relatively small sample size for these groups. A nonparametric Wilcoxon signed rank test for paired data was used to compare postoperative results to the simulated results from preoperative planning.

Results

The peak pressure difference between the measurements made by the two independent investigators was 11 (± 8)%. The difference in calculated contact areas was 9 (± 8)%. The discrepancy mainly appeared in preoperative radiographs when the peak pressure was at the lateral edge of the acetabulum, when it had a magnitude greater than 10 MPa, and when the contact area was less than 10% of the potential contact area. In those cases, the algorithm was sensitive to small changes in the position of the anatomical landmarks.

The effect of osteotomy on anatomical structure

The change in the orientation of the acetabulum mainly occurred in the frontal plane (Tables 2 and 3). Mean F-AC and F-CE angles, indicating lateral coverage of the femur, improved significantly. However, mean S-AC, indicating anterior coverage, did not change significantly. The mean acetabular anteversion (H-AT) was not changed with surgery. The calculated postoperative abductor angle changed moderately (ranging 16.7°–22.9° from the preoperative value set at 21°) due to change in pelvis tilt and/or lateral/medial or superior/inferior movement of the hip center.

Table 2. Clinical and mechanical parameters for each individual

Patients	1	2	3	4	5	6	7	8	9	10	11	12
CP-ratio (%)												
preoperative	24	27	33	37	40	43	25	28	18	36	37	51
postoperative	40	47	48	37	53	54	59	62	67	80	81	89
plan	55	47	48	48	53	52	46	48	48	50	51	49
Peak pressure (MPa)												
preoperative	128	8	8	3	8	6	19	6	13	9	7	4
postoperative	5	3	3	2	4	4	6	3	3	15	17	34
plan	6	3	3	2	4	4	6	3	3	5	4	4
Contact area (mm ²)												
preoperative	20	356	299	751	322	491	180	427	208	336	402	447
postoperative	413	538	475	611	397	541	384	577	598	197	205	98
plan	247	429	475	732	337	481	271	517	421	343	398	449
F-AC (degrees)												
preoperative	27	18	22	21	21	22	18	18	29	19	27	13
postoperative	3	-2	19	6	16	3	-2	-13	9	-7	6	-4
plan	17	9	19	12	14	17	7	10	11	14	17	14
F-CE (degrees)												
preoperative	-1	30	15	27	17	16	4	28	12	14	20	24
postoperative	50	54	31	49	27	46	49	69	41	50	51	52
plan	25	23	19	17	25	21	17	24	27	21	19	20
S-AC (degrees)												
preoperative	-4	-22	-34	-31	-30	-27	-20	-32	-6	2	-28	-31
postoperative	-16	-28	-32	-29	-29	-33	-40	-28	-29	-38	-29	-27
H-AT (degrees)												
preoperative	29	31	20	8	28	21	10	15	32	27	21	17
postoperative	42	37	28	9	26	25	0	13	27	-2	74	29
Q-score												
preoperative	NA ^a	NA	62.5	74.8	75.9	NA	67.5	NA	51.0	NA	74.6	73.8
postoperative	100	NA	68	100	99	86	86	45	99	90	99	NA
Harris												
postoperative	100	100	100	100	100	97	96	52	100	96	100	100

^a Data not available

The relationship between CP-ratio, abductor angle, and contact surface orientation

The line of action of the abductor muscles was varied within a range of -40° – 60° for several radiographs. Simulation of the joint contact pressure showed that CP-ratio increased with abductor angle ($r^2 = 0.94$) when all other parameters were kept constant (Figure 5A). The peak contact pressure was lowest when the CP-ratio was between 0.40 and 0.60. Also, the change in peak contact pressure was least sensitive to the abductor angle for CP-ratios between 0.4 and 0.60 (in Figure 5A, for mid-range of CP-ratio, peak contact pressure varied only by 1.1 MPa when the abductor angle was varied 18°).

When the contact surface was rotated around the joint center while the abductor angle and other parameters were kept constant (Figure 5B), there was a linear relationship ($r^2 = 0.99$) between the

CP-ratio and the acetabular rotation angle. The peak contact pressure was smallest when the CP-ratio was between 0.40 and 0.60. A similar trend was observed for radiographs with different contact areas. Figure 5B shows the existence of an unambiguous minimum contact pressure due to the acetabular rotation. Thus, our local optimization technique can successfully find the optimal acetabular rotation for producing minimum peak contact pressure without getting trapped in local minima.

The effect of osteotomy on mechanical parameters

Osteotomy decreased the peak contact pressure in 9 cases out of 12. While there was a tendency for peak pressure to decrease and contact area to increase with osteotomy, the mean changes in peak pressure and contact area were not statistically

Table 3. The change in patient outcome, mechanics, and acetabular orientation with periacetabular surgery presented as mean (SD)

	Preoperatively n = 12	Postoperatively n = 12	P-value ^a
Patient outcome			
q-score (max = 100)	69 (9) (n = 7)	87 (18) (n = 10) ^b	0.007 (n = 6) ^c
Harris hip score (max = 100)	–	95 (14)	–
Biomechanical parameters			
Peak pressure (MPa)	18 (35)	8 (10)	0.4
Weight-bearing area (mm ²)	353 (181)	419 (172)	0.3
CP-ratio	0.34 (0.09)	0.61 (0.15)	< 0.001
Acetabular orientation			
F-AC	21 (5)	3 (9)	< 0.001
F-CE	17 (9)	46 (11)	< 0.001
S-AC	22 (12)	30 (6)	0.07
H-AT	22 (8)	26 (20)	0.5

^a Paired t-test
^b Two patients complained only about the contralateral, nonoperated hip. Their scores were excluded
^c Both preoperative and postoperative scores were obtained from 6 patients

significant (Table 3). Preoperatively, it was found that the CP-ratio (see methods) was below 0.40 in 9 cases and between 0.40–0.60 in the remaining 3 cases. Postoperatively, 7 cases had a low gradient of pressure distribution (group A, mean/peak pressure 0.55 ± 0.03 , CP-ratio 0.40–0.60) and 5 cases had a high gradient of pressure distribution (group B, mean/peak pressure 0.79 ± 0.12 , CP-ratio outside the range 0.40–0.60).

Outcome for the patients

Clinical outcomes tended to be better for patients

with a low pressure gradient, although the differences were not statistically significant. The grades for preoperative degenerative changes of group A were: 5 grade-0, 1 grade-1, and 1 grade-2. The corresponding grades for group B were: 3 grade-0, 1 grade-1, and 1 grade-2. Although the mean q-score and the mean Harris hip score tended to be higher for group A than for group B, the difference was not statistically significant (Table 4). Power analysis revealed that at least 40 patients per group would have been needed to find a statistically significant difference in either of these two

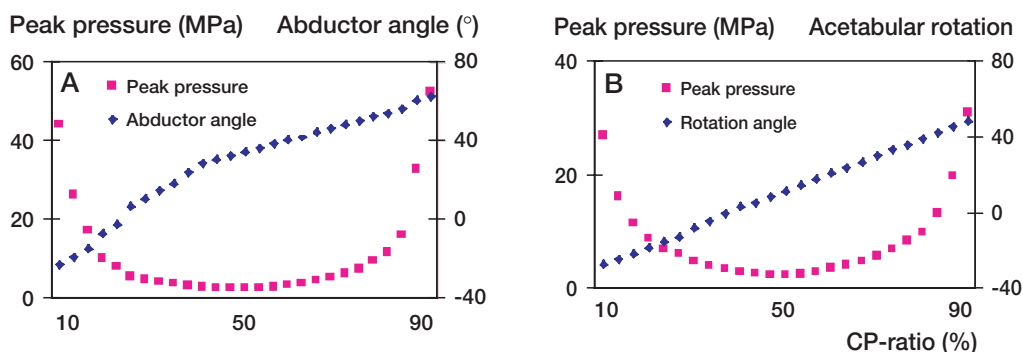
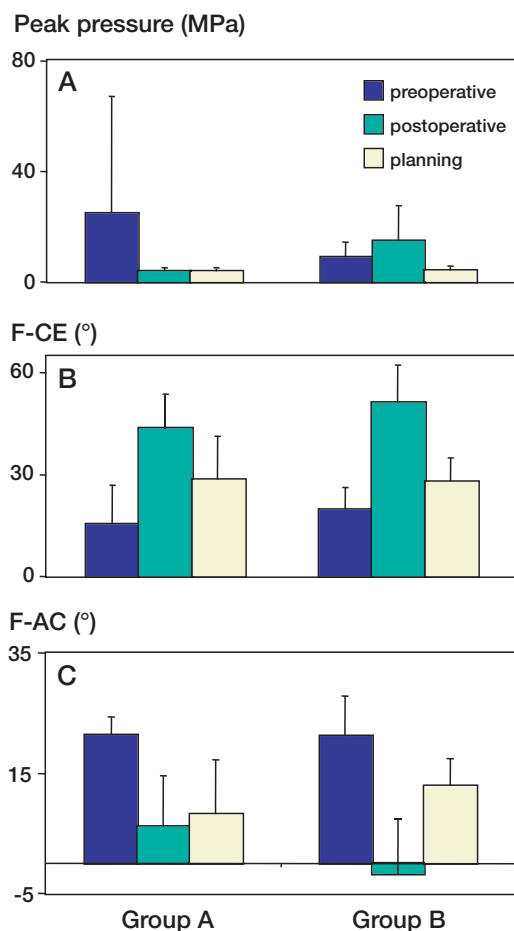


Figure 5. A) When the line of pull of the abductor muscles is varied from -20° to 40° , the CP-ratio increases accordingly. The peak joint contact pressure is minimized when the CP-ratio is at its mid-range, between 40% and 60% approximately. B) When the acetabular contact surface is rotated to up to 35° medially, and up to 45° laterally in the AP plane, the CP-ratio increases linearly from the most medial to the most lateral rotation. The peak joint contact pressure is minimized when the CP-ratio is at its mid-range (between 40% and 60% approximately).

Table 4. Comparison between postoperative results in the low- and high-pressure gradient groups presented as mean (SD)

	Low-pressure gradient n = 7	High-pressure gradient n = 5	P-value ^a
Patient outcome			
q-score (max = 100)	90 (13) (n = 6) ^b	83 (26) (n = 4) ^b	0.8
Harris hip score (max = 100)	99 (2)	90 (21)	0.6
Biomechanical parameters			
Peak pressure (MPa)	3.75 (1.41)	14.7 (12.6)	0.07
Weight-bearing area (mm ²)	480 (87)	335 (234)	0.4
Acetabular orientation			
F-AC	6 (8)	-2 (9)	0.2
F-CE	44 (11)	51 (11)	0.1
S-AC	30 (7)	30 (4)	0.7
H-AT	24 (15)	28 (28)	0.3

^a Non-parametric Mann-Whitney rank sum test for non-paired data
^b In both groups, one patient score was excluded because the patient complained only about the contralateral, nonoperated hip



scores. The analysis was performed for a power of 0.8 and $p < 0.05$.

The main difference between group A and group B was the peak contact pressure. Group B had a negative mean F-AC value (Table 4), which is considered undesirable (Siebenrock et al. 1999). There were no significant changes in the mean values of F-CE, S-AC and H-AT between the low pressure gradient and high pressure gradient groups (Table 4). Group B had a significantly higher mean peak contact pressure than group A. This group had a smaller mean weight-bearing area than group A. However, this difference was not statistically significant (Table 4).

Figure 6. The mean and standard deviations of peak pressures, F-CE, and F-AC angles between group A (CP-ratio between 40% and 60%) and group B (CP-ratio outside 40% and 60%). Preoperative analysis, postoperative analysis, and biomechanical preoperative planning results are shown for each group. For group A, the peak pressures of biomechanical planning and the postoperative results are close to each other, indicating optimal postoperative results when CP-ratio was between 40% and 60%. For group B, the above values are substantially different. The biomechanical planning and the postoperative F-CE angles have no correlation with the two groups and the peak pressures. The postoperative mean F-AC angle for group B was negative, indicating an undesirable situation. This angle was highly variable, indicating that, by itself, it cannot be a substitute for biomechanical parameters.

Mechanical preoperative planning

The predicted peak pressures as a result of preoperative planning of group A were comparable to those calculated from postoperative radiographs (Figures 3B, 3C, and 6A). However, mechanical planning for group B resulted in significantly lower peak pressures ($p < 0.001$) than those calculated from the postoperative radiographs (Figures 4B, 4C, and 6A). Figure 4B is a typical example of the over-correction due to excessive rotation of the acetabulum. In the figure, the normal distance between the reaction force and the medial edge of the acetabulum (point 5) is reduced as compared to the preoperative radiograph. Because of the difference in loading direction, the algorithm distributed most of the spring forces close to the medial edge. The CP-ratio, an indicator of the direction of reaction force and pressure distribution, increased to 80%. Also for group B, the preoperative planning resulted in a lower F-CE angle (Figure 6B) and a larger F-AC angle (Figure 6C) than what was observed postoperatively.

Discussion

While the calculated peak contact pressure decreased after surgery in 9 out of 12 patients, differences between the mean peak contact pressures and the weight-bearing area prior to and after the surgery were not statistically significant. The reason for the nonsignificant differences may have been due to over-correction in some of the cases. The CP-ratio was found to be associated with the mechanical outcome and, to some extent, with F-AC angle after periacetabular osteotomy. However, the optimal joint contact pressure distribution could not be derived from radiographically measured angles, suggesting that the mechanically optimal acetabular orientation cannot always be defined by the angles used for preoperative planning.

The CP-ratio was a proper and unambiguous index for comparison of contact pressure distribution in various cases. Other possible choices for comparing the results were peak contact pressure and/or the location of the peak contact pressure within the contact surface. The peak contact pressure is related to the body weight; thus, it cannot be used for comparison of the results between

patients. Also, while postoperative reduction of the peak contact pressure is necessary, it might not be sufficient for assessing the success of the surgery. For example, if the preoperative analysis shows insufficient lateral coverage (and therefore a high peak contact pressure), under-correction or over-correction, osteotomy may improve the results; but not to a degree that would correspond to a successful surgical outcome. The best mechanical results are achieved when the peak contact pressure is not located at the medial or lateral edge of the contact surface. However, the analyses show that the location of the peak contact pressure is not sensitive to large acetabular rotations. During such rotations, its location moves from the most lateral edge to the medial edge of the source. With further rotations, it remains at the medial edge, but it starts to increase in magnitude exponentially. The CP-ratio is sensitive to correction over much wider ranges than the location of the peak contact pressure. The centroid of contact pressure approaches the edges of the contact surface as the amount of acetabular rotation increases, but never reaches the edge. Thus, the CP-ratio can never equal 0% or 100%.

Simulation of hip-joint loads using AP radiographs was shown to correspond to the F-CE angle in hips with normal structure (Turula et al. 1985). Genda et al. (1995) found that F-CE angles over 20° do not reduce peak contact pressure. In our study, realigning a dysplastic hip joint according to the normal F-CE angles did not consistently reduce the peak contact pressure. Therefore, surgery may not be able to reduce the peak contact pressure in dysplastic hips to a level that is common in normal joints. One reason for this may be the poor overall congruency, as a result of abnormal structure within the joints. Genda et al. did not observe any significant rise in peak contact pressures in cases with remarkably large F-CE angles. Their model for contact surface included the anterior and posterior horns of the joint surface. It is possible that in over-corrected cases, the anterior and posterior horns of the horseshoe shaped contact surface carry a portion of the load even when the patient is standing. Our model may not be valid when describing pressure distribution in cases with significant over-correction, i.e. with negative F-AC angle.

The two-dimensional model used for the current study assumes that the anterior and posterior

halves of weight-bearing area are equal. Ganz et al. (1988) reported an increase in both the lateral coverage and the anterior coverage of the femoral head with periacetabular osteotomy. However, CT measurements of the cases in this study showed that the mean increase in anterior coverage was not significant. Therefore, differences in anterior contact surface are not likely to influence biomechanical analysis of the standing posture dramatically. The study of joint contact pressure distribution during gait further highlights the effect of modifying the anterior contact surface. Change in the direction of the hip resultant force during simulation showed that the surgical alignment must aim at improving both lateral and anterior coverage of the femoral head (Hipp et al. 1999). For the current study, however, the increase of the anterior coverage was patient-specific and varied among individuals. These findings further stress the importance of individual 3D surgical planning based on CT scans. Future studies should incorporate 3D contact surfaces generated from CT scans.

The predicted peak contact pressure from preoperative planning was similar to the postoperative results of group A. The postoperative and preoperative planning values of the F-CE and F-AC angles were similar, suggesting that the realignment angles in this group were set to values that minimized peak pressures. For group B, however, both F-CE and F-AC angles were different from their corresponding predicted values, indicating the over-correction of the realignment angles. It is noteworthy that these two groups could not be distinguished on the basis of the F-AC and F-CE angles. The simulation results support the notion that biomechanics should be included in preoperative planning.

The sample size for this study was relatively small. Because of the risk of type II error, the conclusions based on the patient outcome are preliminary; yet, Group B tended to have lower scores, indicating less satisfactory functional outcome and pain relief. This was supported by the observation of a mean negative value for F-AC angle, which is considered undesirable. Degenerative changes observed before surgery were found to be similar in both groups. These results do not justify any conclusions about the efficacy of periacetabular osteotomy in preventing future degeneration of the joint.

To conclude, radiographic measurement of acetabular alignment does not necessarily fully describe the biomechanical goal of periacetabular surgery. Therefore, allowing estimation of the contact pressure distribution within the joint contact surface may offer a valuable tool in the preoperative planning of hip osteotomies.

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