Acetabular Dysplasia in the Adolescent and Young Adult

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Hip dysplasia is a major cause of osteoarthrosis in adults. Early aggressive osteotomy has the potential of preventing the development of arthritis, but carries with it significant risks. The problem is further complicated because the surgeon has no means of quantifying the dysplastic deformity or of predicting what a particular combination of osteotomies would do to correct the deformity. This study describes methods of quantifying hip-joint geometry in three dimensions based on computed tomography and magnetic resonance studies, and of simulating pelvic osteotomy to correct the deformities. The study analyzes 49 normal hip joints and 20 dysplastic hip joints. The results show that the normal acetabulum is nearly a full hemisphere, which is anteverted 20° and abducted 53°. The normal lateral center–edge angle is 37°. The dysplastic acetabulum is not anterolaterally maldirected, as has been assumed, but is globally dysplastic. Analysis of the individual dysplastic hip joints showed a wide variability. Some patients were deficient globally, some anterolaterally, and some posterolaterally. Methods of analyzing a patient's hip joint, quantifying abnormalities, simulating surgery, and predicting results are demonstrated in a case example.

Treatment of the dysplastic acetabulum in adolescents and young adults presents a difficult clinical and technical challenge to the orthopedic surgeon. Many of these patients are only moderately symptomatic at the time they are diagnosed; however, if left untreated, end-stage degenerative arthritis will eventually occur.[3,16] Delay in treatment ultimately restricts the surgical options to either total hip arthroplasty, which has notoriously poor results in young patients,[2] or arthrodesis. Conversely, early aggressive pelvic osteotomy has significant risks and should not be performed unnecessarily.

There are many pelvic osteotomies that have been developed for the treatment of acetabular dysplasia. These include single,[18] double,[20] and triple[19] innominate osteotomies and periacetabular osteotomies such as the Dial osteotomy.[4,5,22,23] Selecting the appropriate procedure for each patient requires careful preoperative planning.

The present study describes the deformities seen in acetabular dysplasia based on the analysis of hip-joint geometry in a series of patients. The study also demonstrates methods of simulating acetabular osteotomies preoperatively. The methods quantify the severity of the dysplasia and predict the degree of surgical correction that can be expected from a given surgical plan. Clinical application of

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the methods are demonstrated in a case example.

MATERIALS AND METHODS

Computed tomographic (CT) studies of 20 dysplastic hip joints from 17 patients were used in this study. All of the patients were female between the ages of 11 and 41 (mean age, 20). None of the patients had had prior surgery. All of the patients were eventually treated by pelvic osteotomy.

CT studies of 49 normal hip joints from 34 patients between the ages of 11 and 84 (mean age, 53.6) were used to study normal hip joint geometry for comparison. Of these 49 hip joints, a subset of 14 hip joints from 14 females between the ages of 11 and 43 (mean age, 20.7) were also used for comparison. The CT studies of the normal hip joints were obtained for other clinical indications. Hip joints with any evidence of abnormality were excluded from the normal group.

The CT data from each patient group were transferred to a computing facility (VAX 11/785, Digital Equipment, Maynard, Massachusetts), where the images were reformatted and displayed on graphics processors (Lexidata 3700, Adage, Billerica, Massachusetts). The bony surfaces of the femurs and pelvis were calculated automatically based on radiodensity and stored as contours. The contours from sequential images were connected using triangular surface tiles to create three-dimensional models of the bone and joint surfaces.[9,12,13,15,21] The models of the bones could then be displayed in any position or orientation.

Femoral[1,14] and pelvic[8,11-13] reference coordinate systems were used to eliminate the effect of patient positioning on the geometric analysis. The overall orientation of each acetabulum was determined by calculating a plane that best described all of the points on the acetabular rim using a computer optimization algorithm. The vector normal to the opening plane of the acetabulum was calculated and resolved to determine the acetabular abduction and anteversion angles (Fig. 1).[11]

Analysis of the acetabular and femoral head surfaces was based on the subchondral bone surfaces. On each CT image, the subchondral bone surface of the acetabulum and femoral head was defined using equally spaced points (one point every 0.75 mm). Nonarticular portions such as the fovea and acetabular notch were specifically excluded. The articular portions of each hip joint were then represented by approximately 2000 data points on the acetabular and femoral head surfaces.

The surface points were used to define spheres of specific radius and position that best described

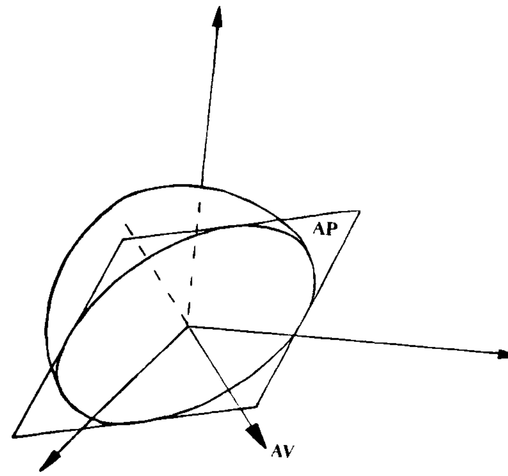


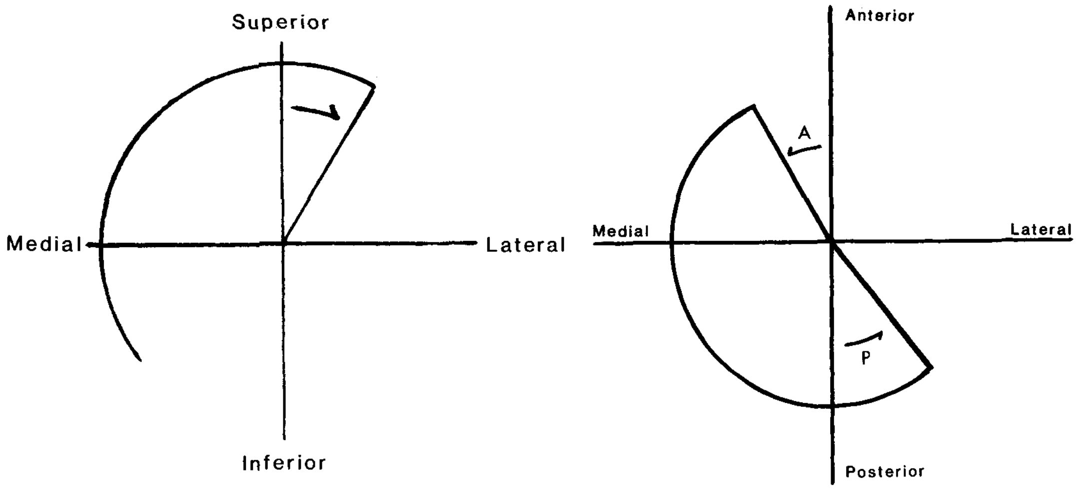
FIG. 1. The overall orientation of the acetabulum is calculated by fitting a plane to data points on the acetabular rim. The normal vector to the acetabular opening plane can be resolved into acetabular anteversion and abduction angles. AP, acetabular opening plane; AV, acetabular vector.

the surfaces of each acetabulum and femoral head using another computer optimization algorithm. The distance between the centers of the femoral head and acetabulum was measured to quantify the presence or absence of concentric reduction of the hip joint.

The ability of the acetabulum to contain the femoral head was quantified using two methods. (1) Lateral, anterior, and posterior center–edge (CE) angles were measured to quantify containment relative to the pelvis. (2) Containment of the femoral head by the acetabular rim was measured by modeling the acetabulum as a portion of a globe.

The lateral CE angle was similar to the CE angle of Wiberg (Fig. 2A). The anterior and posterior CE angles were defined in the transverse plane in an analogous manner[10] (Fig. 2B). As with all other parameters, the CE angles were calculated and not measured directly from transverse CT images, since the latter method did not correct for variability in patient position.[6,8]

Containment of the acetabular rim was also measured by modeling the acetabulum as a portion of a globe with the polar axis of the globe perpendicular to the opening plane of the acetabulum. The globe was divided into longitudes and latitudes, with the location of the acetabular rim, in degrees latitude, calculated for each longitude (Fig. 3).[9,10,12,13] For example, if a latitude angle were 90°, the acetabulum would be a complete



FIGS. 2A AND 2B. Diagrams of CE angles. (A) The lateral CE angle of Wiberg. (B) Anterior and posterior CE angles.

hemisphere in that region. If a latitude angle were 45°, the acetabulum would represent one-fourth of a sphere.

This geometric analysis was performed on dysplastic and normal hip joints. The results were entered into statistical files and automated statistical analyses were performed.

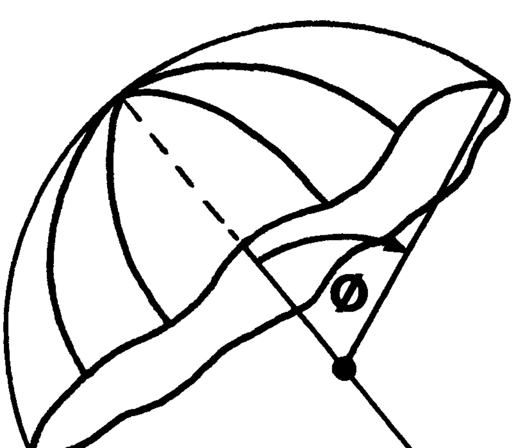


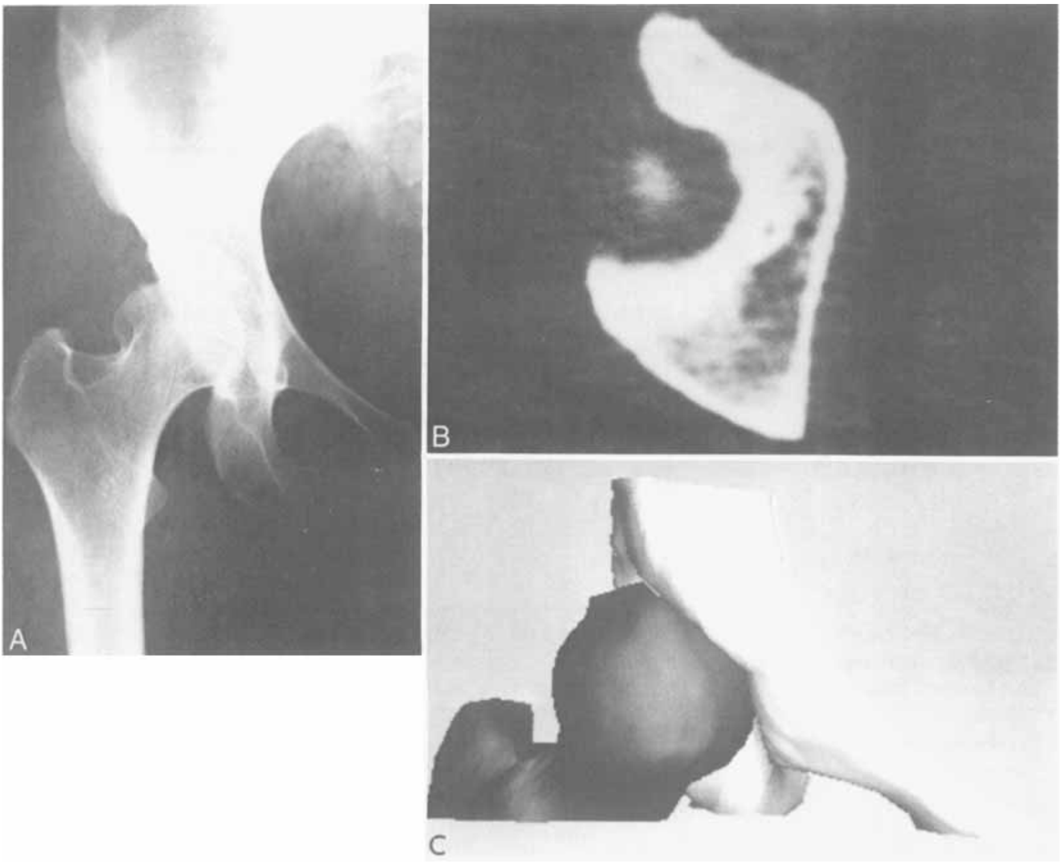
FIG. 3. The latitude angle is the number of degrees from the polar axis to the acetabular rim on any desired longitude. A complete hemisphere would have latitude angles of 90°.

CASE REPORT

A 29-year-old woman who had been treated nonoperatively for congenital dysplasia of the right hip was referred for evaluation. She had noted increasing right groin pain over the previous ten years. Figure 4A shows her hip roentgenogram. Figure 4B shows a CT image through the roof of the acetabulum.

A preoperative geometric analysis was performed and the results are shown in Table 1. The preoperative three-dimensional reconstruction of the hip is shown in Figure 4C. The results of the three-dimensional analysis demonstrated that the acetabulum was excessively abducted (10° above normal) and that containment was severely and globally deficient. The deficiency was greater anteriorly than posteriorly. Specifically, the lateral CE angle was +5.2° (normal, 37.5°), the anterior CE angle was −75.5° (normal, −27.5°), and the posterior CE angle was −6.9° (normal, 14.5°). The containment angles were 14°–45° below normal. The patient's acetabulum formed only one-third of a hemisphere rather than a nearly complete hemisphere as in the normal acetabulum.

The Salter innominate and Dial osteotomies were simulated preoperatively to predict the normalizing effects of these proposed procedures. The innominate osteotomy was simulated by dividing the pelvis from the right sciatic notch to the right anterior inferior iliac spine. The distal pelvic fragment, which includes the acetabulum, was rotated 30° around an axis defined by the pubic symphy-



FIGS. 4A–4C. Preoperative studies of a 29-year-old woman with residual hip dysplasia and pain. (A) AP roentgenogram. (B) CT image through the acetabular roof. (C) Three-dimensional computer graphic reconstruction.

sis and the right sciatic notch.[17] The results of the osteotomy simulation are shown in Figure 5A and Table 1.

The Dial osteotomy was simulated by dividing the acetabulum from the surrounding pelvis using a spherical cut with a 4-cm radius centered at the center of the joint surface of the femoral head. The free acetabular fragment was adducted 29° and retroverted 20°. The results of the simulated Dial osteotomy are shown in Figure 5B and Table 1.

Results of the 30° innominate osteotomy simulation demonstrated that although the acetabular abduction would be improved by 13°, the global acetabular deficiency was so severe that the lateral CE angle would still be only 18.4°. Results of the simulated Dial osteotomy demonstrated dramatic improvement in the lateral CE angle from 5.2° to 37.5°, and the anterior and posterior deficiencies were more balanced. For these reasons, the Dial osteotomy was selected and performed in this particular case.

Figures 6A and 6B show anteroposterior (AP) roentgenograms immediately and two years after surgery. Figure 6C shows a CT image through the acetabular roof. Figure 6D shows the postoperative three-dimensional reconstruction. The preoperative and postoperative results are compared in Table 1.

RESULTS

The normal hip joint was concentrically reduced to within 1 mm. The normal acetabulum was anteverted 20° (±7°) and abducted

TABLE 1. Hip-Joint Geometric Analysis and Simulation of Surgery

Variables	Case Example Preop.	Case Example Postop.	Adult Normals Mean	Adult Normals SD	Postsimulated Innominate	Postsimulated Dial
Acetabular						
Anteversion (degrees)	30.20	41.60	20.40	7.10	4.40	17.50
Abduction (degrees)	63.20	34.90	53.00	6.30	45.30	36.40
Radius (cm)	2.31	2.41	2.55	0.28	2.31	2.31
Femoral head						
Radius (cm)	1.64	1.64	2.35	0.32	1.64	1.64
CE angle (degrees)						
Lateral	5.20	40.60	37.50	10.00	18.40	32.60
Anterior	−75.50	−61.20	−27.50	7.90	−45.00	−58.50
Posterior	−6.90	19.60	14.50	7.30	−30.90	−18.80
Containment angle (degrees)[a]						
0°—Anterior	44.70	70.40	90.20	6.20	49.40	49.90
30°	57.00	67.80	85.30	7.60	61.40	52.80
60°	68.20	77.70	82.20	8.40	69.50	64.00
90°—Superior	68.40	75.50	83.10	7.20	63.70	69.00
120°	58.00	73.10	87.30	6.50	56.00	60.30
150°	53.30	69.40	90.10	6.00	52.20	55.10
180°—Posterior	52.90	68.00	89.00	6.50	54.60	52.70
Distance between acetabular and femoral head centers (cm)	00.60	00.13	00.09	0.30	—	—

[a] In degrees latitude per degree longitude.

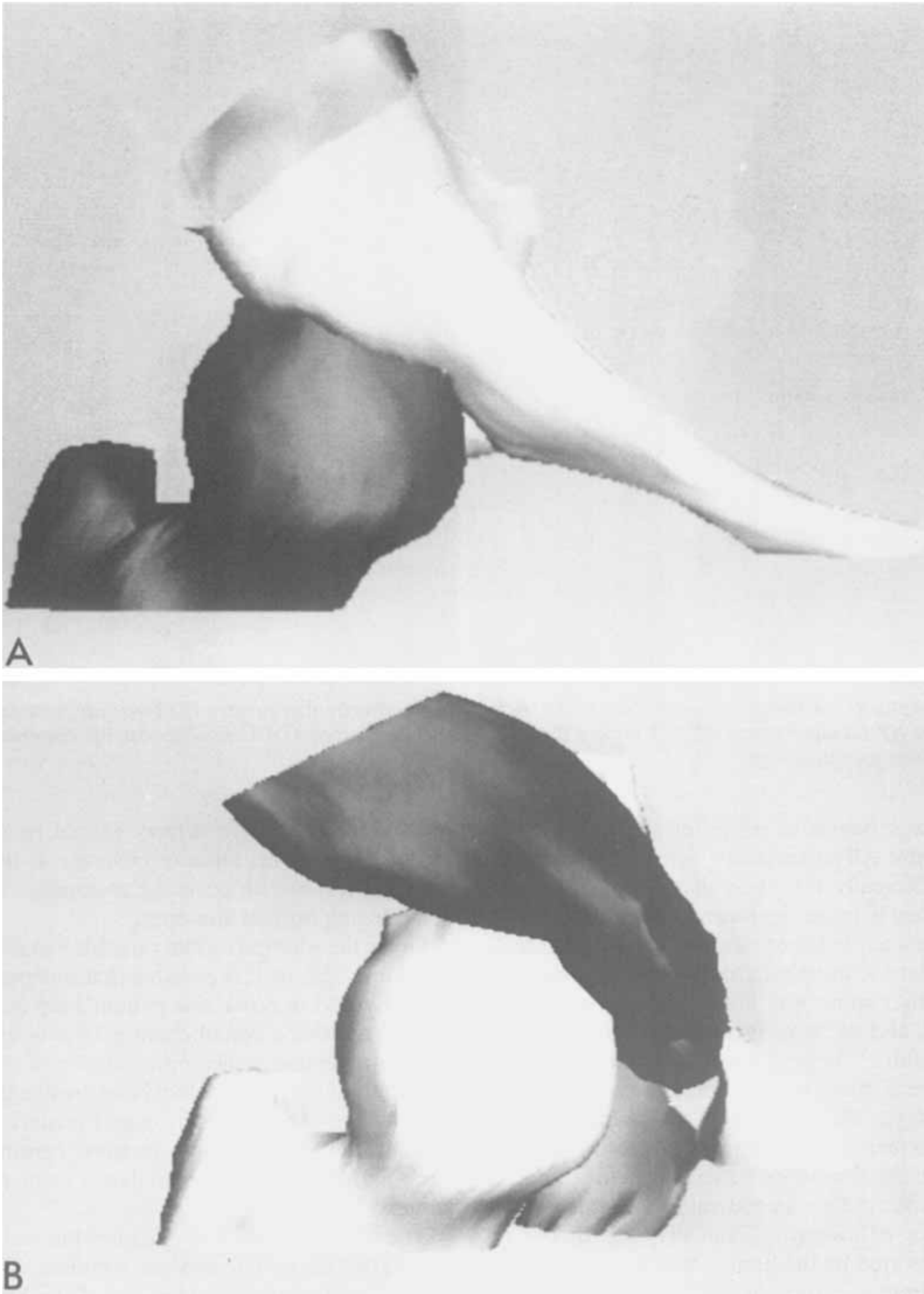
53° (±6°). The lateral CE angle was 37° (±10°). The containment angle measured between 82° and 90°, or nearly a perfect hemisphere. These findings are summarized in Table 2.

The dysplastic hip joint was not concentrically reduced. The acetabular anteversion was not statistically different from normal, and the acetabular abduction was only moderately increased to 62° (±6°). In contrast, the CE angles were markedly decreased compared to normal. The lateral CE angle was decreased by 22°, which was significant by two-tailed *t*-test ($p < 0.001$). Similarly, the anterior CE angle was decreased by 31° ($p < 0.001$), and the posterior CE angle was decreased by 25° ($p < 0.001$). Finally, analysis of the containment angles showed that rather than a hemisphere, the dysplastic acetabulum was only one-third of a sphere.

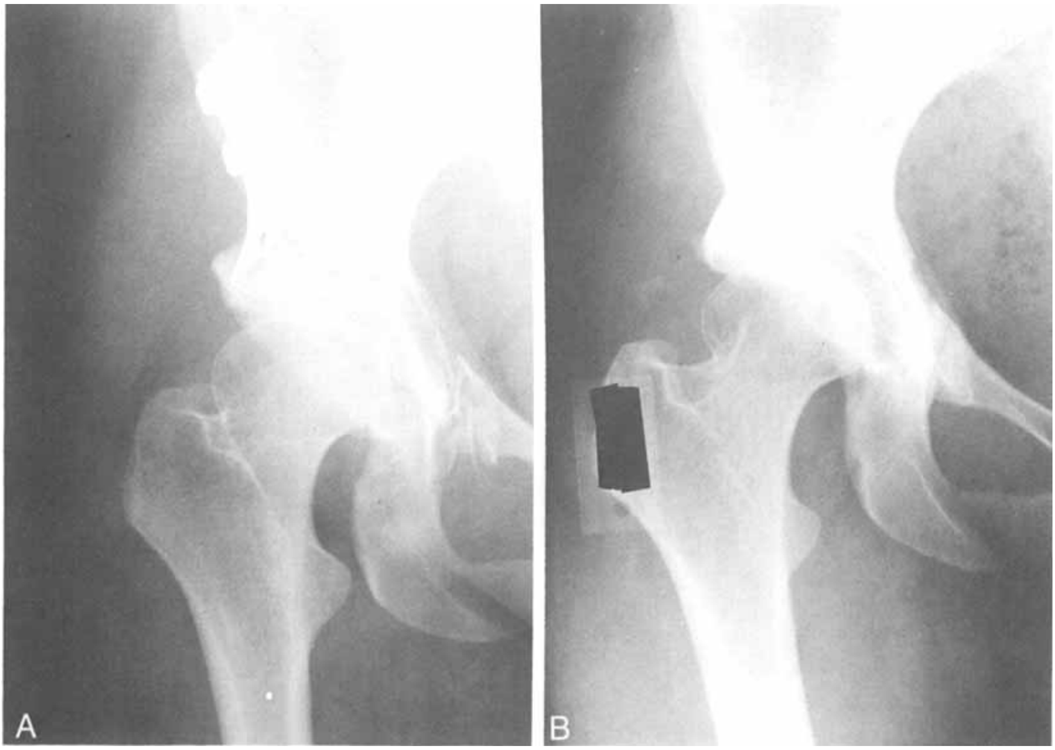
Analysis of the individual dysplastic hip joints revealed a wide variability. Seven acetabula were more deficient anterolaterally than posterolaterally, six were more deficient posterolaterally than anterolaterally, and seven had symmetric, global deficiency.

DISCUSSION

The primary deformity in the dysplastic hip of adolescents and young adults is not anterolateral acetabular maldirection as has commonly been assumed. The primary deformity in acetabular dysplasia is a global dysplasia, with poor anterior, lateral, and posterior containment of the femoral head. Individual patients vary widely, with some patients having a greater degree of anterior acetabular deficiency and others having a



FIGS. 5A AND 5B. Preoperative computer graphic simulation of pelvic osteotomy surgery. (A) Single innominate osteotomy. (B) Dial osteotomy.



FIGS. 6A–6D. Postoperative studies (A) AP roentgenogram shortly after surgery. (B) Two-year postoperative AP roentgenogram. (C) CT images through the acetabular roof. (D) Three-dimensional computer graphic reconstruction.

greater degree of posterior acetabular deficiency. All patients have lateral deficiency.

Clinically, it is likely that the anterior deficiency is more significant than the posterior deficiency in the etiology of osteoarthritis secondary to acetabular dysplasia. Clearly, the lumbar spine was not designed for bipedal gait, and the same is true for the human acetabulum. In level gait and strain climbing, there is much more acetabular coverage posterior to the direction of the resultant force than there is anterior to it. Therefore a small amount of anterior deficiency is much more significant than an equivalent amount of posterior deficiency. Clinically, this theory is supported by the finding that the earliest degenerative cysts seen by CT scanning are often found anterosuperiorly on the acetabulum and femoral head. If this is true, the goal of reconstructive surgery should be to slightly overcorrect anterior coverage at the expense of posterior coverage as opposed to reproducing normal anatomy.

Given the wide individual variability in acetabular dysplasia, it is possible that one procedure could improve one patient's hip and worsen another's. Small changes in anteversion/retroversion or flexion/extension of the acetabulum during osteotomy can drastically improve or worsen anterior and posterior containment. In response to these results, each patient is routinely analyzed prior to surgery.

The case example demonstrates the techniques that are used to analyze, simulate, and plan a reconstructive osteotomy of the hip. Comparison of diseased and normal hip joint geometries identifies the anatomic deficien-

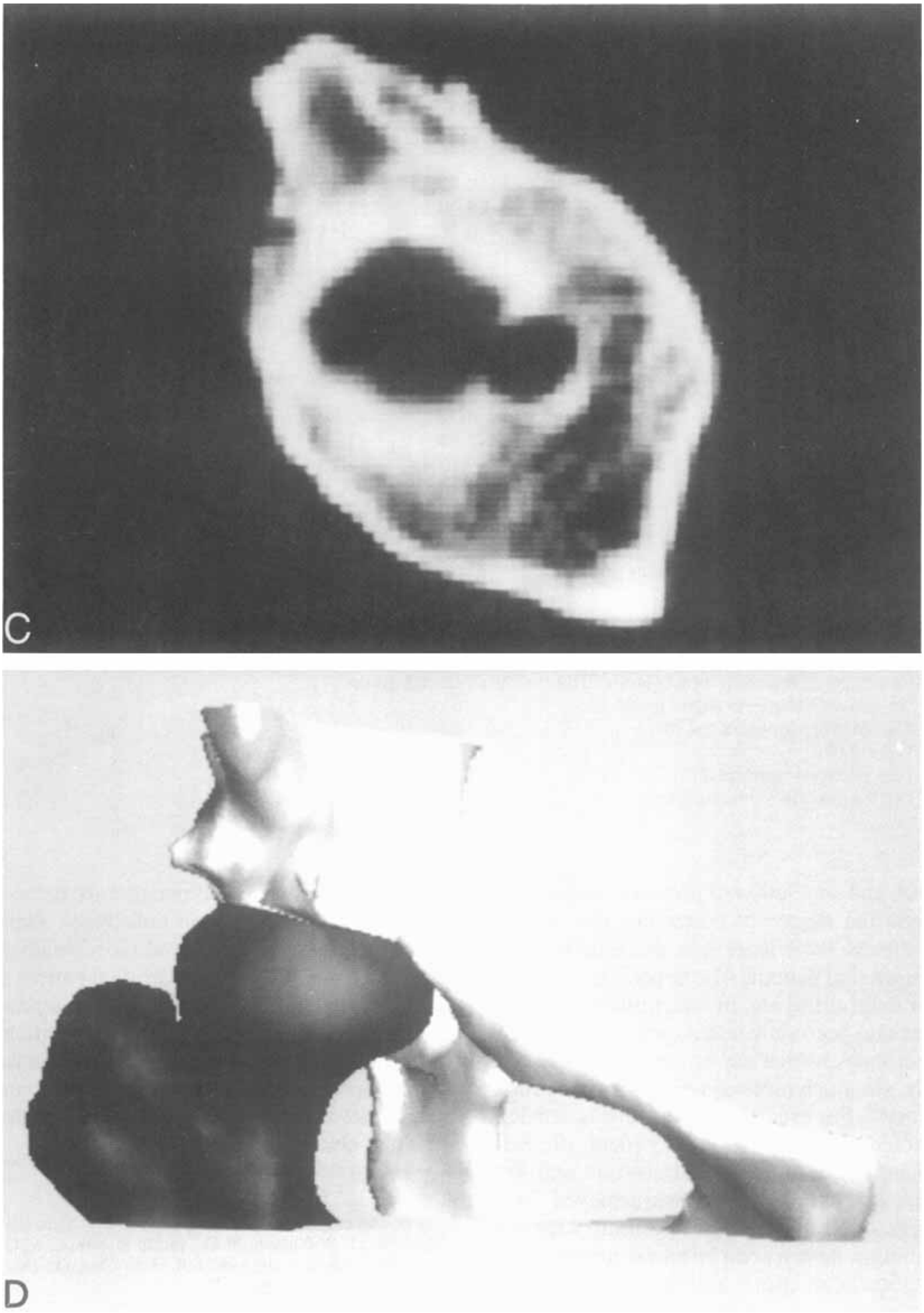


FIG. 6. (*Continued*).

TABLE 2. Geometric Analysis of Dysplastic and Normal Hip Joints[a]

	CDH		All Normals		Female Normals	
Variables	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Acetabular						
Anteversion (degrees)	20.50	10.70	20.40	7.10	17.70	6.70
Abduction (degrees)	61.70	5.90	53.00	6.30	57.20	4.30
Radius (cm)	2.60	0.36	2.55	0.28	2.18	0.25
Femoral head						
Radius (cm)	2.09	0.27	2.35	0.32	1.92	0.24
CE angle (degrees)						
Lateral	5.70	6.30	37.50	10.00	31.00	7.30
Anterior	−54.80	18.30	−27.40	7.90	−32.20	7.80
Posterior	−9.90	7.60	14.50	7.30	5.20	9.50
Containment Angle (degrees)[b]						
0°—Anterior	67.40	6.70	90.20	6.20	88.20	4.90
30°	61.00	7.90	85.30	7.60	79.40	5.10
60°	57.10	9.10	85.20	8.40	74.20	6.70
90°—Superior	59.70	9.10	83.10	7.20	77.50	5.20
120°	70.90	8.50	87.30	6.50	83.20	5.50
150°	62.20	12.30	90.10	6.00	89.00	5.40
180°—Posterior	55.70	9.90	89.00	6.50	86.40	5.30
Distance between acetabular and femoral head centers (cm)	0.47	0.25	0.09	0.03	0.15	0.11

[a] Statistical comparisons were between CHD and the all-normal group.
[b] In degrees latitude per degree longitude.
* Statistically significant $p < 0.01$.
** $p < 0.001$.
† No statistical significance.
CDH, congenitally dysplastic hip.

cies, and simulation of proposed surgery predicts the degree of correction that can be achieved. Experience with this technique has shown that patients who appear to have similar deformities are, in fact, quite different. It has also been shown that common pelvic osteotomies, which are conceptually very simple, are much more complex when examined closely. For example, if a patient is deficient posteriorly, it is possible to rotate the deficient area into the lateral position and find that little or no correction was achieved. Similarly, small changes in the position of the acetabulum have a great effect on containment, especially anteriorly and posteriorly.

It is imperative that all patients are not assumed to have the same deformity; each patient should be considered individually.[7] Failure to understand an individual patient's dysplasia will result in performing an inappropriate operation or an appropriate operation in an incorrect manner. Even when the goals of an operation are clearly defined, the accurate achievement of those goals remains difficult and challenging.

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