Use of Computed Tomographic Reconstruction in Planning Osteotomies of the Hip

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Certain deformities of the hip joint seem to predispose the hip to the development of osteoarthrosis. Successful surgical correction of these deformities before the onset of osteoarthrosis requires accurate characterization of the anatomic deviations from normal as the first step in planning corrective osteotomy. Three-dimensional computed tomography (CT) reconstruction in planning reconstructive hip osteotomy has most often been employed in developmental dysplasia of the hip. Computed tomography scanning with three-dimensional reconstruction can characterize the often complex deviations from normal in shape and attitude of acetabulum and femoral head in cases with residual hip dysplasia. Three-dimensional reconstruction also allows simulation of redirectional femoral or pelvic osteotomies to facilitate precise application of newer powerful surgical techniques for reorienting the acetabulum.

Certain patterns of hip deformity associated with developmental hip disease predispose the hip to the development of osteoarthrosis. Whereas primary prevention of the three major developmental hip diseases predisposing to osteoarthrosis of the hip (developmental dysplasia, Perthes' disease, and slipped capital femoral epiphysis) would be ideal, a large number of patients will develop residual deformity from these conditions. The current challenge is to consider those patients for treatment who have the deformities that predispose to osteoarthrosis, but have not yet developed irreversible joint changes associated with osteoarthrosis. In these patients, at least theoretically, some means of normalizing their hip anatomy might prevent or delay the development of osteoarthrosis. This is the concept of reconstructive osteotomy, in which the primary aim of the surgical treatment is to improve the long-term prognosis of the hip joint.[21]

Reconstructive osteotomy should be performed when the following criteria are present: (1) The patient is certain to develop osteoarthrosis without the reconstructive procedure; (2) the reconstructive osteotomy is certain to prevent the osteoarthrosis; and (3) the morbidity from the reconstructive procedure is acceptable.

The patterns of developmental hip deformity that predispose a patient to osteoarthrosis have become more clear. There are two major groups of deformities. The first group, the *reconstructive* group, consist mainly of malalignments without irreversible changes in the normally smooth contours of acetabular and femoral hyaline articular surfaces. There is no roentgenographic incongruity and there is full range of motion clinically. By normalizing the malaligned acetabulum and/or proximal femur, the pathomechanics associated with the malalignment can theoretically be corrected and the otherwise inevitable progression to osteoarthrosis obviated.

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The second category of deformities, the *salvage* group, largely represents a later stage of many deformed hips that once were in the reconstructive category. In this clinical group, irreversible deformity and intraarticular changes have occurred. In this group, no realigning osteotomy is likely to improve the mechanics of the joint enough to totally arrest the progression to osteoarthrosis. Osteotomy has a role in this group as well, although the concepts of its application in salvage situations are not so straightforward as in the reconstructive group. Incongruity is usually present in hips in this group. Computed tomography analysis can be employed to study the congruence in these salvage hips.[8]

Although some of the roentgenographic parameters of the normal hip have been recognized for some time,[23] it is only recently that certain important deviations from normal occurring on the plain anteroposterior (AP) roentgenograph in certain developmental hip diseases have been recognized.[6,17]

In developmental dysplasia of the hip, the most common primary diagnosis associated with osteoarthrosis of the hip,[1] there has been a tremendous increase in knowledge regarding the pathoanatomy of the dysplastic hip, beginning with certain new planar images[7,9,18] and, more recently, more sophisticated knowledge resulting from radically different imaging techniques.[5,8,10–12]

Recent experience with CT studies of the hip with three-dimensional reconstruction has included the following: (1) characterization of normal hips in adolescents and young adults; (2) characteristic deviations from normal in hip dysplasia; (3) preoperative simulation of various redirectional osteotomies; and (4) limited experience in analyzing the results of redirectional osteotomies executed with the help of these planning techniques.

MATERIALS AND METHODS

Computerized tomographic studies of 30 dysplastic hips from 23 patients were used in this study. Twenty-eight of the 30 patients were female between the ages of 11 and 41 years (mean, 19 years). Two of the patients had had prior surgery. All of the patients were eventually treated by pelvic osteotomy. Computerized tomographic studies of 49 normal hip joints from 34 patients between the ages of 11 and 84 years (mean, 53.6 years) 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 years (mean, 20.7 years) 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 any abnormality were excluded from the normal group. As previously reported,[11] the CT data was reformatted and displayed on graphics processors with the bony surfaces of the femora and pelvis calculated automatically based on radiodensity and stored as contours. Three-dimensional models of the bone and joint surfaces were created by connecting the contours from sequential images using triangular surface tiles, allowing models of the bones to be subsequently displayed in any position or orientation.

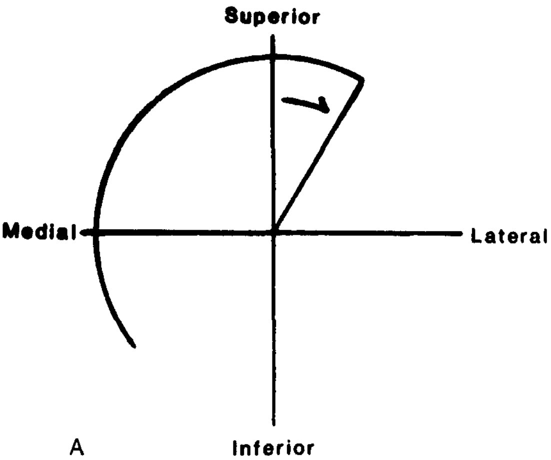
The ability of the acetabulum to contain the femoral head was quantified using the following two methods:[11] (1) Lateral, anterior, and posterior center edge angles were used to quantify containment relative to the pelvis. The lateral center edge angle (Fig. 1A) is analogous to the angle of Wiberg, with the anterior and posterior center edge angles are defined in the transverse plane in an analogous manner (Fig. 1B). The anterior center edge angle usually correlated well with the anterior center edge angle displayed on the planar false profile lateral view of Lequesne.[9]

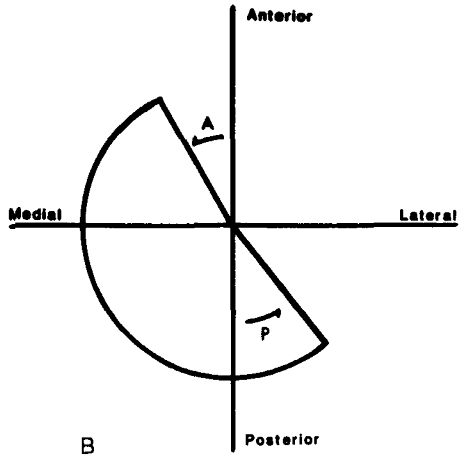
(2) Containment of the femoral head by the acetabular rim was also measured by modeling the acetabulum as a portion of a globe (Fig. 2).[11] Latitude angles are generated with a latitude angle of 90° representing a hemispheric acetabular shape in that plane.

The proximal femur was also characterized with regard to neck-shaft angle and anteversion. The proximal femur will not be discussed further in this report, although reconstructive intertrochanteric osteotomy is planned in a manner analogous to pelvic osteotomy.

RESULTS OF CT RECONSTRUCTION ANALYSIS OF NORMAL HIPS

The normal hip joint was noted to be concentrically reduced, with the centers of the femoral head and acetabulum always within 1 mm of each other. The normal acetabulum





FIGS. 1A AND 1B. Diagrams of CE angles. (A) Lateral CE angle (Wiberg). (B) Anterior and posterior CE angles. (Reproduced with permission from Murphy, S. B., Kijewski, P. K., Millis, M. B., and Harless, A.: Acetabular dysplasia in the adolescent and young adult. Clin. Orthop. 261:214, 1990.)

was anteverted 20° (± 7°) and abducted 53° (± 6°). The lateral center edge angle was found to be 37° (± 10°). The containment angle measured between 82° and 90°, nearly a perfect hemisphere.[11]

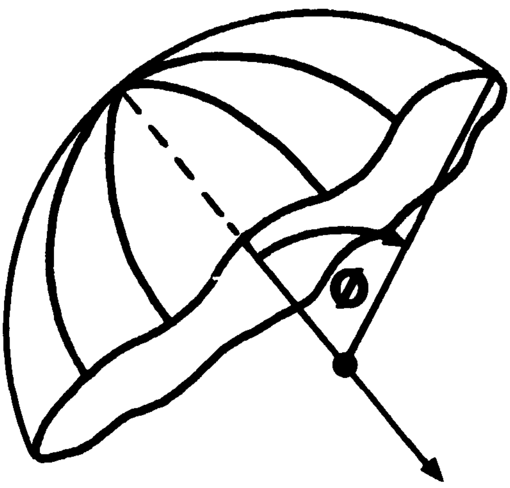


FIG. 2. Characterization of the acetabulum as a portion of a globe. The latitude angle represents the number of degrees from the apex of the acetabulum to the acetabular rim in a given plane. A hemispheric acetabulum would generate latitude angles of 90° in each plane. (Reproduced with permission from Murphy, S. B., Kijewski, P. K., Millis, M. B., and Harless, A.: Acetabular dysplasia in the adolescent and young adult. Clin. Orthop. 261:214, 1990.)

PREOPERATIVE CHARACTERIZATION OF ACETABULAR DYSPLASIA

The CT analysis of the 30 dysplastic hips (23 patients) studied revealed the following. Typically, the dysplastic hip joint was not concentrically reduced. The acetabular anteversion was not statistically different from normal. The acetabular abduction, which was 53° (± 6°) in normals, was only moderately increased in the dysplastic hips, to 62° (± 6°).

The striking deviations from normal in the dysplastic hips were in two categories: the center-edge angles and the containment angles. The lateral C-E angle was decreased from normal by 22° to an average value of 15°. Similarly, the anterior center-edge angle was decreased by 31°, and the posterior center-edge angle was decreased by 25° ($p < .001$ in each case).

Analysis of the containment angles showed that rather than a hemisphere, the dysplastic acetabulum was typically only about one third of a sphere. Analysis of the individual dysplastic hip joints revealed a great variability in the areas of major deficiency. All dysplastic acetabula had major lateral deficiency. Of these 30 dysplastic acetabula studied extensively, ten acetabula were more deficient anterolaterally than posterolaterally, ten were more deficient posterolaterally than anterolaterally, and ten had symmetric global deficiency.[11]

PREOPERATIVE SIMULATION OF OSTEOTOMIES

The Salter[15] innominate and Dial spherical acetabular osteotomies[20] are simulated preoperatively to predict the normalizing effects of these proposed procedures on the dysplastic acetabulum.[11] Innominate osteotomy is simulated by dividing the pelvis from the right sciatic notch to the right anterior inferior iliac spine and rotating the distal pelvic fragment 30° anterolaterally around an axis defined by the pubic symphysis and the right sciatic notch.[14]

The Dial spherical acetabular osteotomy is 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 is then reoriented in various ways, depending on the particular characteristics of the dysplastic acetabulum being studied. Depending on the character of the dysplasia in the individual joint, the best compromise in reorienting the acetabular joint surface vertically over the femoral head is chosen. In the simplest case of pure abduction deformity of the acetabulum, with the acetabulum otherwise of normal size and shape, a purely adducting osteotomy would yield normalization. In general, the acetabular dysplasia is more complex, involving global deficiency. Usually a multiaxis reorientation is simulated to optimize coverage without aggravating deficiencies. Extension and adduction of the acetabular fragment are commonly employed to correct major anterior and lateral deficiency. Some rotation

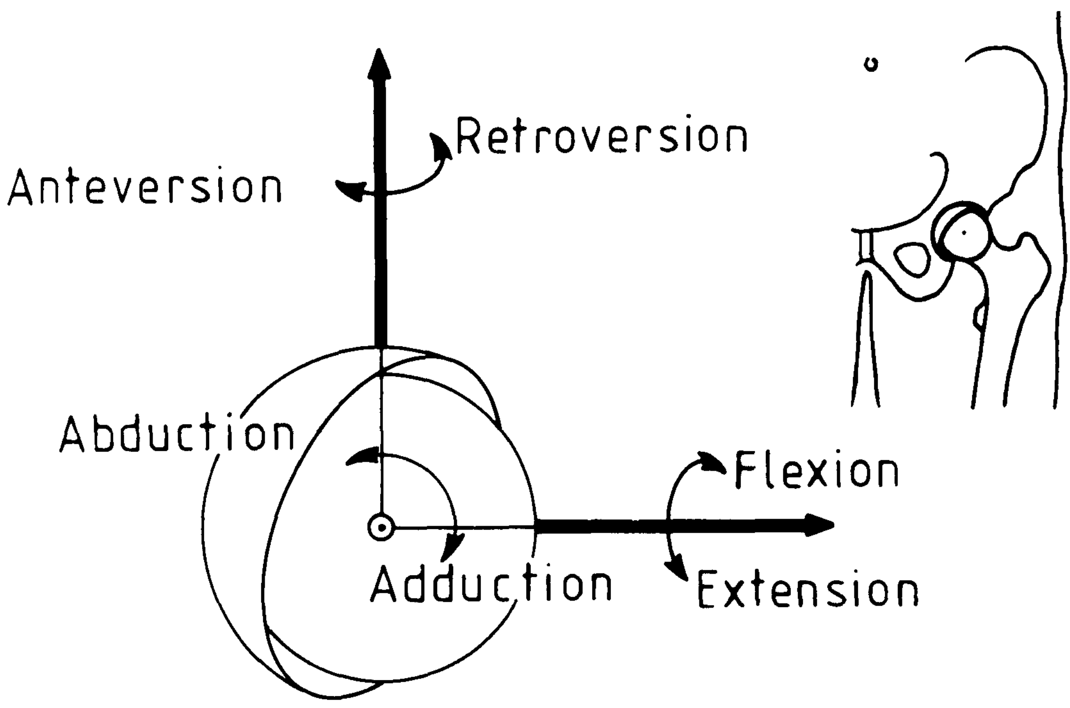


FIG. 3. Axes of rotation for osteotomies that redirect the acetabulum. (Reproduced with permission from Klaue, K., Wallin, A., and Ganz, R.: CT evaluation of coverage and congruency of the hip prior to osteotomy. Clin. Orthop. 232:15, 1988.

around an axis parallel to the long axis of the body can also be added as needed (Fig. 3).

SURGICAL TECHNIQUES

Salter innominate osteotomies were performed as classically described, using an oblique incision and an anterior approach to the hip joint, with mandatory iliopsoas tenotomy, rigid Steinmann pin fixation, and early mobilization.

Spherical acetabular osteotomies in this study were executed as described by Wagner,[19,20] through a modified semilunar anterolateral skin incision and an anterior approach, using pronged plate fixation and early mobilization, again as described by Wagner. All acetabular osteotomies in this group were Wagner Type I involving reorientation of the free acetabular fragment without intrapelvic lengthening or medialization.

CLINICAL RESULTS

The paucity of postoperative three-dimensional reconstructions in the innominate osteotomy group precluded direct comparison with the spherical acetabular osteotomy group.

In general, the results suggested the limitations of innominate osteotomy in normalizing acetabula with moderate to high-grade dysplasia.[12] The relatively limited role of single innominate osteotomy in this mature group of patients may lie in the fact that the fixed axis of rotation for this osteotomy is not necessarily in the optimum plane for correcting the major deficiency of the given dysplastic acetabulum. In addition, the older patient has relatively limited elasticity in the symphysis pubis, somewhat limiting the amount of correction possible in the older patient through a single innominate osteotomy.

The spherical acetabular osteotomies were satisfying in the amount and degree of freedom of reorientation that was achieved surgically. The limiting factor in true normalization of the hip joint in this patient group is the reduction from normal in the capacity of these dysplastic acetabula (absolute hypoplasia), as reflected in the low containment angles.

Only future studies will determine to what degree acetabular augmentation may be useful in enhancing the results of osteotomies to reorient the dysplastic acetabulum.

DISCUSSION

With increasing recognition of the relatively malignant nature of residual acetabular dysplasia in predisposing to osteoarthrosis of the hip, increasing efforts are being exerted to characterize in three dimensions the deviations from normal in this clinical condition. Recent investigations of the three-dimensional deformity in acetabular dysplasia have identified a global dysplasia in the usual case, with reduced anterior, lateral, and posterior containment of the femoral head, presenting with various deficiencies in various patients, with all patients having some lateral deficiency.[11]

Coincident with defining the character of the acetabular dysplasia in a given patient has come the ability to simulate preoperatively the effect of various realigning pelvic osteotomies.

The goal of preoperative osteotomy simulation has been reached using three-dimensional CT by the CT-directed application of powerful surgical techniques of acetabular redirection,[4,16,20] with the spherical acetabular osteotomy[20] being the current procedure of choice.

In the future, it is anticipated that analogous methods of analysis using magnetic resonance imaging[5] will be employed, perhaps in a role complementary to CT.

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REFERENCES

1. Aronson, J.: Osteoarthritis of the Young Adult Hip: Etiology and Treatment. Instr. Course Lec. 35:119, 1986.
2. Bombelli, R.: Osteoarthritis of the Hip, Ed. 2. Berlin, Springer, 1983.

3. Cooperman, D., Wallensten, R., and Stulberg, S. D.: Acetabular dysplasia in the adult. Clin. Orthop. 175:79, 1983.
4. Ganz, R., Klaue, K., Vinh, T. S., and Mast, J. W.: A new periacetabular osteotomy for the treatment of hip dysplasias. Technique and Preliminary Results. Clin. Orthop. 232:26, 1988.
5. Guidera, K. J., Einbecker, M. E., Berman, C. G., Ogden, J. A., Arrington, J. A., and Murtagh, R.: Magnetic resonance imaging evaluation of congenital dislocation of the hips. Clin. Orthop. 261:96, 1990.
6. Harris, W. H.: Etiology of osteoarthritis of the hip. Clin. Orthop. 213:20, 1986.
7. Johnston, C., Wenger, D., Roberts, J. M., Burke, S. W., and Roach, J. W.: Acetabular coverage: Three-dimensional anatomy and radiographic evaluation. J. Ped. Orthop. 6:548, 1986.
8. Klaue, K., Wallin, A., and Ganz, R.: CT evaluation of coverage and congruency of the hip prior to osteotomy. Clin. Orthop. 232:15, 1988.
9. Lequesne, M., and de Seze, S.: Le faux profile du bassin: Nouvell incidence radiographique par l'etude de la hanch. Rev. Rhum. Mal. Osteoartic. 28:643, 1961.
10. Murphy, S. B., Kijewski, P. K., and Millis, M. B.: Unpublished data.
11. Murphy, S. B., Kijewski, P. K., Millis, M. B., and Harless, A.: Acetabular dysplasia in the adolescent and young adult. Clin. Orthop. 261:214, 1990.
12. Murphy, S. B., Kijewski, P. K., Millis, M. B., Hall, J. E., Simon, S. R., and Chandler, H. A.: The planning of orthopaedic reconstructive surgery using computer-aided simulation and design. Comput. Radiol. 12:33, 1988.
13. Pauwels, F.: Biomechanics of the Normal and Diseased Hip. Berlin, Springer, 1973.
14. Rab, G. T.: Biomechanical aspects of Salter osteotomy. Clin. Orthop. 132:82, 1978.
15. Salter, R. B.: Innominate osteotomy in the treatment of congenital dysplasia and dislocation of the hip. J. Bone Joint Surg. 43B:518, 1961.
16. Stulberg, S. D., Cooperman, D., and Wallenston, R.: The natural history of Legg-Calve Perthes disease. J. Bone Joint Surg. 63A:1095, 1981.
17. Stulberg, S. D., Cordell, L. D., Harris, W. H., Ramsey, P. L., and MacEwen, G. D.: Unrecognized Childhood Hip Disease: A Major Cause of Idiopathic Osteoarthritis of the Hip. *In* Amstutz, H. (ed.): The Hip, St. Louis, C. V. Mosby, 1975.
18. Tonnis, D.: Congenital Dysplasia and Dislocation of the Hip. Berlin, Springer, 1987.
19. Wagner, H.: Osteotomies for Congenital Hip Dislocation. *In* Evarts, C. M. (ed.): The Hip. St. Louis, C. V. Mosby, 1976.
20. Wagner, H.: Experiences with spherical acetabular osteotomy for the correction of the dysplastic acetabulum. Prog. in Orthop. Surg. 2:131, 1978.
21. Wagner, H.: Personal communication.
22. Weinstein, S. L.: Natural history of congenital hip dislocation (CDH) and hip dysplasia. Clin. Orthop. 225:62, 1987.
23. Wiberg, G.: Studies on dysplastic acetabula and congenital subluxation of the hip joint with special reference to the complication of osteoarthritis. Acta Chir. Scand. 83(Suppl.): 58, 1939.