Computed Tomography Evaluation of Stability in Posterior Fracture Dislocation of the Hip

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Measurements of the percentage of remaining posterior acetabulum on computed tomography (CT) scan (the Acetabular Fracture Index) in posterior fracture dislocations of the hip were evaluated to determine the stability of the joint. All hips with less than 34% of the remaining posterior acetabulum were unstable. Hips with greater than 55% were stable. Between these values, hips were either stable or unstable. A statistical analysis demonstrated highly significant differences in the average remaining posterior acetabulum between the stable and unstable group. These findings were based on a review of 26 patients with posterior fracture dislocations of the hip (Epstein Type I–IV injuries) combined with CT scan analysis. The clinical status of hip stability was correlated with the Acetabular Fracture Index, and this provided the basis for the study. A simple linear measurement of the remaining posterior acetabulum on CT (the Approximate Acetabular Fracture Index) can be done easily by a physician, and this closely approximates the true remaining acetabular arc. Seven of ten unstable hips in 31 Epstein Type I–V patients showed femoral head subluxation of 0.5 mm or more on CT scan, whereas none of the 21 stable hips had demonstrable subluxation. Risk analysis provided a means of predicting hip stability for individual patients.

Evaluation and treatment of the posterior wall in posterior fracture dislocations of the hip was improved since the advent of computed tomography (CT). In the past, posterior hip fracture dislocation was evaluated with plain roentgenograms, using Judet views. Recent studies have shown that CT can detect intraarticular fracture fragments[11–13] and associated fractures of the femoral head[7,13] better than plain roentgenograms. In comparison with conventional tomography, CT is more sensitive in detecting fractures of the acetabular roof and the posterior acetabular lip, loose bone fragments, and abnormalities of the hip joint.[5,18] In addition, appropriate treatment is significantly influenced by the additional information provided by CT.[12] These studies confirm the importance of CT for the complete evaluation of the posterior fracture dislocation of the hip.

Epstein,[4] in a long-term review of posterior fracture dislocations of the hip, recommended primary open reduction with removal of loose fragments and stabilization of an unstable hip joint. The determination of hip stability as dictated by the size of the posterior fragment was not specifically addressed, and the study was done when CT scanning was not available for evaluation of acetabular fractures. Tile[16] stated that posterior fracture dislocations should be reduced under general anesthesia where the postreduction "personality of the fracture" can be assessed. If the hip is unstable, then open reduction is indicated. Letournel[9] emphasized the complete repair of the acetabulum, including the achievement of congruence of

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the articular surface. Rosenthal and Coker[10] concluded that the presence of intraarticular bone fragments does not necessarily indicate open reduction unless the fragments are trapped in the weight-bearing area, and that a poor result will ensue if an "incompetent posterior wall" is present. Larson[8] stressed both stability and anatomic reduction (congruity) and described a postreduction stability test. A longitudinal force is applied toward the hip with the hip flexed at 30°–40°. An unstable reduction will redislocate the hip, which means that a significant segment of the acetabular dome must be fixed to ensure stability. Despite these contributions, it is still difficult to define what size of posterior fragment will render a patient's hip unstable after closed reduction.

Authors such as Epstein,[2] Brav,[1] Stewart and Milford,[14] Urist,[17] and Thompson and Epstein[15] stated that open reductions are justified to remove loose bodies and to restore hip stability by internal fixation of large fragments of the posterior rim. However, terms such as large fragment, significant segment, incompetent posterior wall, and hip stability are all subjective assessments in the orthopedic literature. The evaluation of the significant posterior fragment, which determines hip stability, can be done easily with CT. Keith *et al.*[6] presented the first analysis of hip stability and its correlation to the size of the posterior fragment using CT scan. They measured the size of the acetabular fragment in 16 cadaver iatrogenic fractures and correlated the size of the fragments to hip stability at 90° flexion and 20° adduction. The measurement on the CT scan was from the medial wall (*i.e.*, ilioischial line), to the outermost portion of the posterior acetabulum at the level of the fovea. Using the normal contralateral side, they calculated the percentage of posterior acetabular wall fractures. Hips with more than 42% of the posterior wall removed were unstable (*i.e.*, less than 58% remaining) and those with less than 21% removed (*i.e.*, more than 79% remaining) were stable. This method of measurement, however, includes the medial wall in the calculation. It is also believed that normal muscle tone in a patient may provide additional stability and therefore alter these data.

Posterior fracture dislocations of the hip are controversial with regard to the determination of hip stability after the initial reduction. Various authors have described different clinical methods and criteria for determination of hip stability, and likewise the literature contains many different descriptions of the amount of fractured posterior acetabulum required for a stable hip, including (1) incompetent posterior wall; (2) large posterior fragment; (3) significant segment of acetabular dome; and (4) personality of the fracture. These terms are helpful, but roentgenographic evidence is needed to assist the physician in difficult cases. Lateral roentgenograms are helpful but sometimes difficult to interpret and usually are taken with the hip in the extended (stable) position, therefore subtle subluxations can easily be missed. Objective data are needed to evaluate these injuries when considering open reduction and internal fixation of the posterior acetabulum.

MATERIALS AND METHODS

The classification of Epstein[3] was used in the description of posterior fracture dislocations of the hip as follows: Type I, no fracture or a minor fracture of the posterior acetabular rim; Type II, a single large fracture of the posterior rim; Type III, a comminuted fracture of the posterior rim; Type IV, a fracture of the posterior rim and the floor (medial wall); and Type V, a fracture of the femoral head.

Fifty-seven patients with posterior hip dislocations were seen from October 1979 to May 1984. Central and anterior dislocations were not included in this group. Thirty-four of these patients had CT scan of the involved hip joint during the first week of hospitalization for evaluation of the fractures and location of loose fragments within the joint. Thirty-one patients (23 men and eight women) had complete roentgenographic studies available for retrospective evaluation. The average age was 34 years (range, 18–74 years). The number of patients in each class is as follows: Type I, two patients; Type II, four patients; Type III, 12

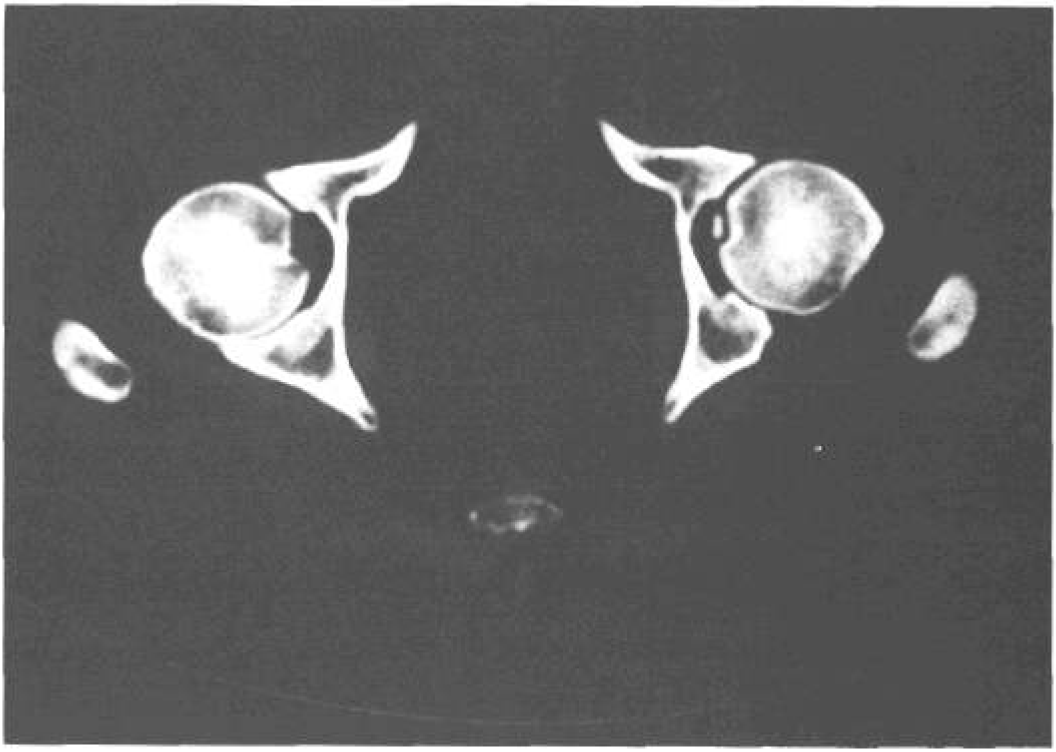


FIG. 1. Acetabular fracture on a CT scan from which measurements are made.

patients; Type IV, eight patients; and Type V, five patients.

All 31 patients had their hip reduced within 24 hours of injury. These patients were tested for hip stability at a position of 90° hip flexion, 0° hip adduction, and 0° hip rotation.

CRITERIA FOR HIP STABILITY

The hip was considered unstable if any one of the following criteria was met: (1) clinical hip instability demonstrated at 90° hip flexion, 0° hip adduction, and 0° hip rotation (this test was performed after closed reduction, or within four days after injury in the case of the five transferred patients); (2) hip instability demonstrated at 90° hip flexion, 0° hip adduction, and 0° hip rotation after arthrotomy for removal of loose fragments in the joint; (3) redislocations; or (4) subluxation of the hip, demonstrated of plain films.

RADIOGRAPHIC CRITERIA

The following three factors were analyzed using CT: (1) femoral head subluxation; (2) displacement of the posterior fragment after reduction of the hip; and (3) percentage of remaining intact posterior acetabulum (Acetabular Fracture Index). On the fracture side, the section that demonstrated the largest amount of fractured posterior acetabulum (*i.e.,* the smallest intact remaining posterior acetabulum) was selected. This section was usually at the level of the central acetabular fossa. A contralateral section was selected and matched by comparing femoral head sizes and the configuration of the fovea and the acetabular fossa and pelvis. These sections were used for measurements.

Femoral head subluxation was measured from the anteriormost portion of the acetabulum (on the two selected sections) to the femoral head (Figs. 1 and 2). A difference of 0.5 mm between the fractured side and the normal contralateral side was considered significant subluxation. The amount of displacement of the posterior acetabular fragment after hip reduction was measured from the fracture margin on the remaining intact posterior articular surface to the nearest fracture fragment (Fig. 2 and Table 1).

The Acetabular Fracture Index (AFI) was de-

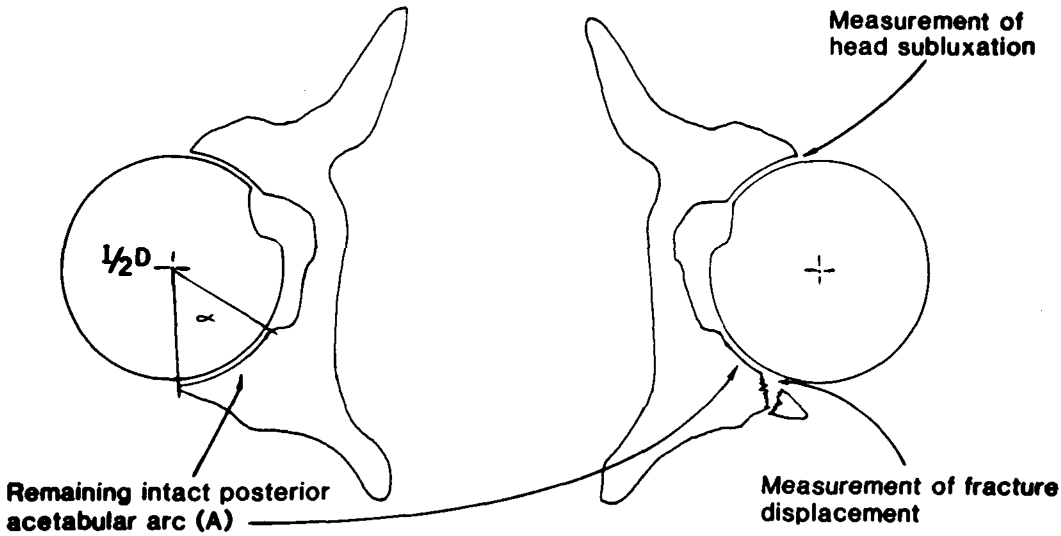


FIG. 2. The three criteria measured.

fined as the percentage of remaining intact posterior acetabular arc (A). It is described by the relationship (Fig. 2):

$$A = \frac{\pi D \alpha}{360}$$

Furthermore,

$$\frac{A_{(\text{Fracture})}}{A_{(\text{Normal})}} = \frac{\dfrac{\pi D \alpha_{(\text{Fracture})}}{360}}{\dfrac{\pi D \alpha_{(\text{Normal})}}{360}} \times 100$$

= Acetabular Fracture Index

where A = the acetabular arc, D = the diameter, and α = the angle formed by the lines to the posterior acetabular margins. This relationship was simplified because the diameter and π are the same for the numerator and denominator. This formula was further reduced to:

$$\frac{\alpha_{(\text{fracture})}}{\alpha_{(\text{normal})}} \times 100 = \text{Acetabular Fracture Index (AFI)}$$

AFI was measured using a plastic template (Fig. 3) to match the corresponding circumference of the acetabulum on the two CT scan sections previously described (Fig. 4). The center of the acetabular arc was marked on the template, and this point was transcribed onto both CT scan sections (Fig. 4). Using the center of the acetabular arc, an angle (α) was made to two points determined by the posterior acetabulum (Fig. 5) on each of the

TABLE 1. AFI and Average Fracture Displacement for Each Fracture Type

Epstein Classification	*No. of Patients*		*Average Acetabular Fracture index*		*Average Displacement of Major Fragment (mm)*	
	Stable	*Unstable*	*Stable*	*Unstable*	*Stable*	*Unstable*
I	2	0	100.0	—	0	0
II	3	1	75.1	44.8	1.67	2.00
III	7	5	51.4	35.2	4.70	4.75
IV	5	3	57.3	30.5	2.20	6.00
V	4	1	89.4	72.4	2.25	2.00

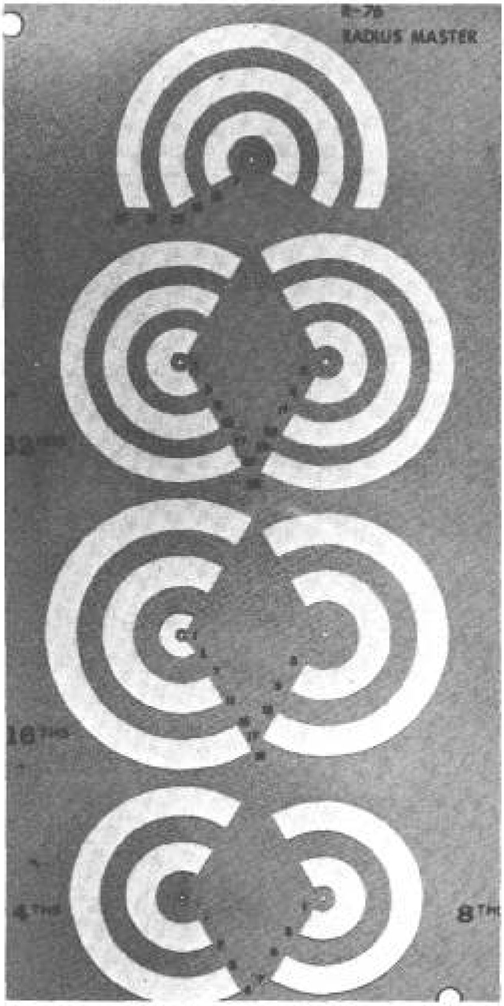


FIG. 3. Template used in measurement of the AFI.

two CT scan sections. This angle was measured on the fractured and normal contralateral CT scan sections with a goniometer. The Approximate Acetabular Fracture Index (ApAFI) is an approximation of the AFI. Only a ruler is needed to calculate this value on the two selected CT scan sections. A straight line measurement (Fig. 6) is made of the remaining intact posterior acetabular arc on the fractured side and on the contralateral normal side. The ratio of these two measurements times 100 reliably approximates the true AFI. In other words,

$$\frac{L_{(\text{fracture})}}{L_{(\text{normal})}} \times 100 = \text{ApAFI}$$

The geometric relationship between the ApAFI and the AFI was determined to validate the ApAFI (Fig. 7). A mathematical calculation of the ApAFI for the 31 patients, including the percentage of error between the AFI and the ApAFI, is shown in Table 2. The average error of the ApAFI was 4.3% (range, 0.4%–9.9%) in 27 patients who demonstrated an AFI other than 100 or 0. This means that the ApAFI overestimates the true AFI by 4.3%. The advantage of the ApAFI is the simplicity of measurement.

RESULTS

STABLE HIPS

Twenty-one patients did not meet the criteria for unstable hips and therefore were classified as having stable hips. The test for hip stability was performed after reduction, and definite treatment was based accordingly. Fourteen patients were treated with Buck's skin traction (5–7 pounds) for several days before starting ambulation. Six patients were treated with skeletal traction (average of 12 pounds) for an average of three and one-half weeks before starting ambulation. These six patients had a stable hip examination; however, low-weight skeletal traction was used to treat their acetabular fractures (Type IV, 3 patients; Type V, 2 patients; Type III, 1 patient). The one remaining patient had six weeks of skeletal traction (30 pounds) for an ipsilateral femur fracture. All 21 patients were classified as having stable hips before the definitive treatment was planned. Three of the 21 patients had arthrotomies for removal of intraarticular loose fragments and then had an intraoperative hip stability examination, which confirmed a stable hip joint.

UNSTABLE HIPS

Ten patients met at least one of the criteria described for hip instability. Five patients had a preoperative hip examination that established instability at 90° hip flexion, 0° hip adduction, and 0° hip rotation. These patients had open reduction and internal fixa-

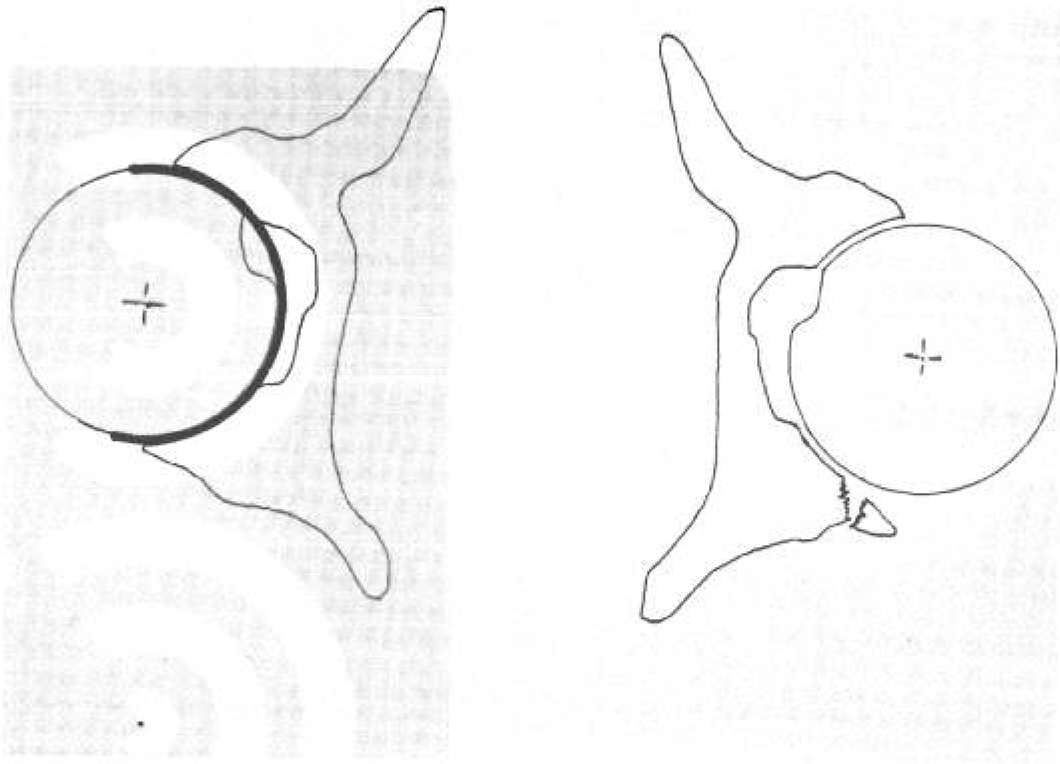


FIG. 4. The correct placement of the template on the acetabulum.

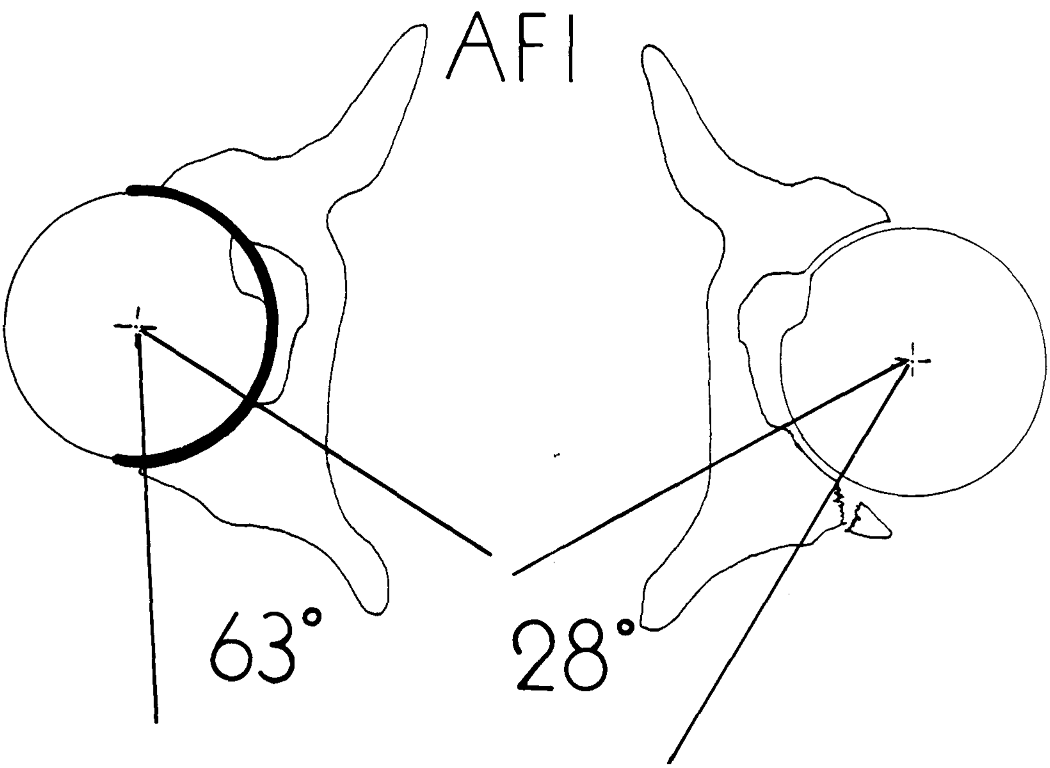


FIG. 5. The center of the acetabular arc is marked and the angle (α) is created by the remaining intact posterior acetabulum.

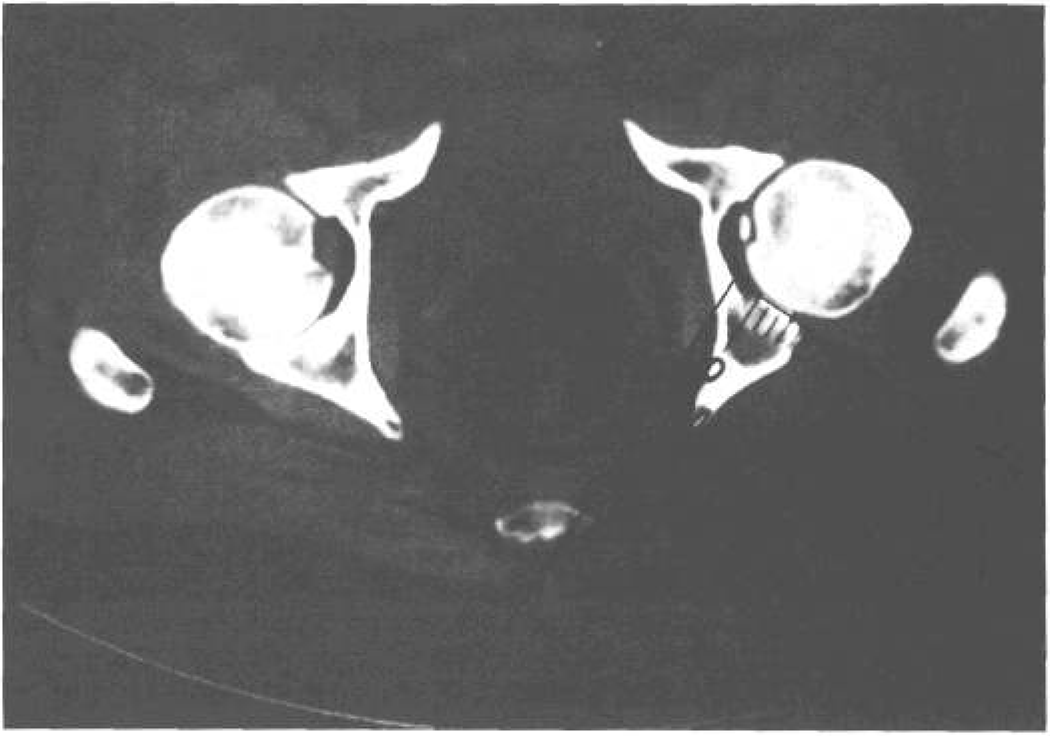
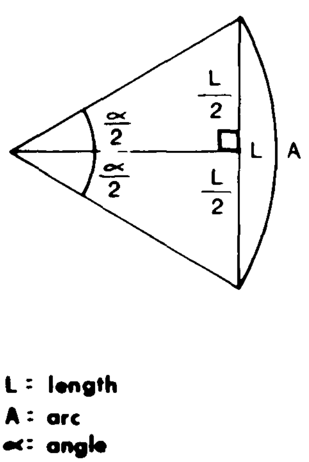


FIG. 6. The straight line measurement of the posterior acetabulum is used for calculation of the ApAFI.

tion of the posterior fragment with association (AO) screws, which subsequently resulted in a stable hip joint. Three patients had an unstable hip on physical examination but were treated nonoperatively in skeletal traction and abduction braces. Two of these



$$L = 2r \sin\left(\frac{\alpha}{2}\right)$$

Therefore,

$$\frac{L_{FX}}{L_{NOR}} = \frac{2r \sin\left(\frac{\alpha FX}{2}\right)}{2r \sin\left(\frac{\alpha NOR}{2}\right)} = \frac{\sin\left(\frac{\alpha FX}{2}\right)}{\sin\left(\frac{\alpha NOR}{2}\right)}$$

FIG. 7. The relationship of the straight line measurement L to the acetabular arc A.

TABLE 2. The Acetabular Fracture Index (AFI) and the Percent Error of Measuring the Approximate Acetabular Fracture Index (ApAFI)

Patients	*Type*	$\frac{\alpha_{Fracture}}{\alpha_{Normal}}$	$\frac{L_{Fracture}}{L_{Nor}}$	*Acetabular Fracture Index (AFI)*	*Approximate Acetabular Fracture Index (ApAFI)*		*% Error Between ApAFI and AFI*
Stable Hip							
1	II	44/55	4.8/5.9	80.0	81.2		1.5
2	IV	24/67	2.0/5.3	35.8	37.7		5.2
3	III	48/54	3.9/4.3	83.9	89.6		6.8
4	III	28/63	3.1/6.6	44.4	46.3		4.3
5	III	27/58	2.2/4.6	46.6	48.2		3.3
6	III	42/61	4.6/6.5	68.8	70.6		2.6
7	II	43/58	4.1/5.4	74.1	75.6		2.0
8	III	38/85	3.6/7.5	44.7	48.2		7.8
9	II	54/76	4.3/59	71.1	73.7		3.7
10	III	25/68	2.4/6.2	36.8	38.7		5.2
11	IV	38/60	4.7/7.1	63.3	65.1		2.9
12	IV	20/50	2.2/5.4	40.0	41.1		2.7
13	IV	52/66	6.3/7.8	73.8	80.5		9.0
14	III	23/67	2.9/7.9	34.3	36.1		5.3
15	IV	47/59	4.4/5.5	73.7	81.0		9.9
16	I	66/66	7.8/7.8	100.0	100.0		0.0
17	I	63/63	6.6/6.6	100.0	100.0		0.0
18*	V	61/84	4.8/6.4	72.6	75.9		4.5
19*	V	58/64	6.2/6.7	90.6	91.4		0.9
20*	V	50/53	4.0/4.2	94.3	94.7		0.4
21*	V	63/63	6.6/6.6	100.0	100.0		0.0
Unstable hip						*Hip Subluxation on CT (mm)*	
1	IV	48/87	3.9/66	55.2	59.1	.5	7.0
2	III	28/52	2.7/4.9	53.8	55.2	1.0	2.6
3	IV	3/52	0.5/4.2	5.8	6.0	1.0	3.0
4	III	18/64	1.5/5.0	28.1	29.5	1.0	5.1
5	III	18/60	2.0/6.4	30.0	31.3	.5	4.3
6	III	23/50	2.5/5.4	46.0	47.2	.5	2.5
7	II	26/58	2.1/4.6	44.8	46.4	0	3.6
8	III	12/67	1.3/7.0	17.9	18.9	0	5.8
9	IV	0/55	0/5.9	0	0	3.0	0
10*	V	42/58	4.5/6.1	72.4	73.9	0	2.1

α, angle; L, linear acetabular fracture index.
* Type V patients were eliminated from AFI evaluation.

patients had hip subluxation on plain roentgenograms and refused operative treatment, and one patient was not medically cleared for surgery.

The remaining two patients had late redislocations, despite initial stability on clinical examination. One of these two patients had juvenile rheumatoid arthritis with poor mus-

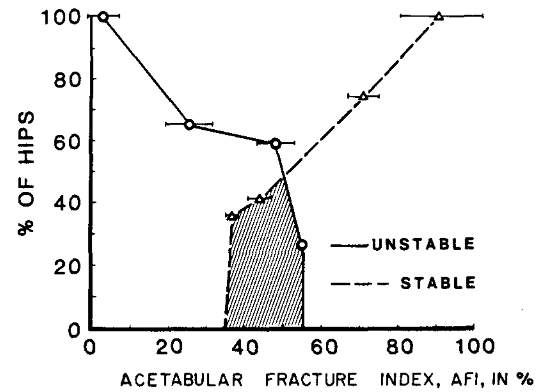


FIG. 8. The distribution of the 26 patients with Epstein Fracture Types I–IV. Points on the stable and unstable curves represent the mean values of the AFI of the patients with similar indices. The range of those indices is also shown for each point.

cle tone and redislocated the hip three weeks after the initial injury (a large Type III fracture). The other patient had open reduction and internal fixation of an ipsilateral femoral neck fracture (reduced in retroversion) and subsequently redislocated the hip one week later.

Femoral Head Subluxation

Femoral head subluxation greater than 0.5 mm occurred in seven of ten (70%) unstable hip patients, as measured on CT scan. The range of hip subluxation was 0.5–3 mm. None of the 21 stable hip patients showed subluxation.

Amount of Fracture Displacement

The average displacement for each fracture type does not differ between the stable and unstable groups, with the exception of Type IV fractures (Table 1). It is not known why the Type IV fractures show this difference. The range of fracture displacement of stable hips was 0–8 mm and of unstable hips was 2–10 mm.

Acetabular Fracture Index (AFI)

This analysis showed significant differences between the stable and unstable groups (Table 2). Seventeen patients were stable after reduction and nine patients were unstable. Type V fractures (5 patients) were not included in this analysis because the fractured femoral head contributed to the instability and confused the analysis of the posterior wall. No unstable fractures had more than 55.2% of the posterior acetabular wall intact. Conversely, no stable fractures had less than 34.3% of the posterior wall of the acetabulum intact (Fig. 8). The mean values of the stable and unstable groups were 63% and 35% of intact posterior wall, respectively. Assuming a normal distribution of these data, these two groups were significantly different (Student's t-test, $p < .002$). Chi-square test of the two groups also indicated statistically significant differences ($p < .005$). The overlap region for the two groups was from 34.3% to 55.2% of intact posterior wall. Seven of the 17 stable hips and four of the nine unstable hips (or 42% of the patients with Type I–IV fractures) were in this area of overlap between the two groups (Fig. 8). Only one patient had no intact posterior wall and only two patients had 100% of the posterior wall intact (although a very small fracture was evident).

Approximate Acetabular Fracture Index (ApAFI)

A statistical analysis using 95% confidence limits and the chi-square test was done to find the maximum and minimum error that would occur in the ApAFI when estimating the AFI (Table 3). The mean angle (α) from the normal unfractured side of the 31 patients was used. Two standard deviations of this angle (α) gave the minimum angle of 43.0° and the maximum angle of 82.2°. The maximum error at two standard deviations was 9%. This is consistent with the error calculated for the ApAFI in the 27 patients with a fractured acetabulum. This means that statistically the ApAFI will not be in error more than 9% at 95% confidence limits. In addition, the mean statistical error was 4.2%, which compares favorably with the calcu-

TABLE 3. Percent Error of $\frac{L_F}{L_n}$ in Approximating $\frac{A_F}{A_N}$

$\frac{A_F}{A_N} = \frac{\alpha_F}{\alpha_N}$	*Acetabular Fracture index (AFI)*	$\frac{L_F}{L_N}$ *43.0° (Minimum 95% Confidence)*	$\frac{L_F}{L_N}$ *62.6° (Mean α)*	$\frac{L_F}{L_N}$ *82.2° (Maximum 95% Confidence)*
0	0	0 (0%)	0 (0%)	0 (0%)
0.1	10	0.102 (2%)	0.105 (5%)	0.109 (9%)
0.2	20	0.205 (2%)	0.210 (5%)	0.217 (9%)
0.4	40	0.408 (2%)	0.417 (4%)	0.430 (8%)
0.6	60	0.609 (2%)	0.620 (3%)	0.634 (6%)
0.8	80	0.807 (1%)	0.815 (2%)	0.826 (3%)
1.0	100	1.0 (8%)	1.0 (0%)	1.0 (0%)

Mean α_{normal} = 62.6° (N = 31).
α_{normal} ± 2 Standard Deviations (95% Confidence) = 43.0° and 82.2°.

lated mean error of 4.3% from the 27 patients with acetabular fractures (Types I–IV).

In an effort to reconstruct a curve that represents the possibility that a given percentage of intact posterior wall would place a given patient into the stable or unstable group, a relative risk analysis was performed, using the ApAFI (Fig. 9). This analysis was carried out at the 95% confidence limits. The patients were grouped into ranges of values for the percentage of intact posterior acetabulum for the chi-square test. The first group consisted of patients who had 0%–18% of the posterior wall intact; the second group, 18%–39%; the third group, 39%–56%; the fourth group, 56%–76%; and the fifth group, 76%–100%. From this, the data were normalized to assume that in the total population of posterior dislocated hips there would be large enough numbers that the unstable and stable groups would essentially be equal in size for purposes of calculation. From this, an odds ratio was calculated, based on the percentage of patients in each subgroup who were either stable or unstable. The odds ratios were then reconverted into percentages of probability at the 95% confidence limits (which represent almost two standard deviations from the mean).

Figure 9 allows one to predict the stability or instability of a fractured acetabulum with a given ApAFI. For example, a patient with an ApAFI of 20.0 has an 80% probability of being unstable. Conversely, a patient with an ApAFI of 70.0 has a 75% probability of being stable.

DISCUSSION

Determination of hip stability from physical examination after initial closed reduction

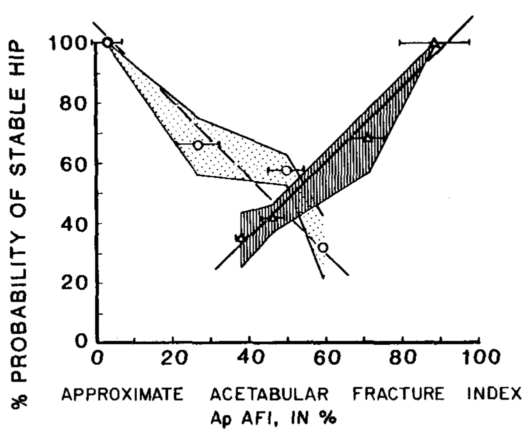


FIG. 9. A relative risk analysis showing the probability that a given acetabular fracture with a given ApAFI will be stable or unstable, carried out at 95% confidence limits.

depends on a number of factors: (1) position of the hip at the time of examination; (2) axial force applied to the involved femur during examination; (3) extent of soft tissue damage (*i.e.*, muscular and nerve); (4) use of general anesthesia *versus* intravenous sedation; and (5) presence of intraarticular fragments. All of these factors play a role in the subjective assessment. However, despite the nonstandardized clinical criteria for determining hip stability, the physical examination remains extremely important. Although recommendations for the amount of hip flexion used for determining hip stability are beyond the scope of this study, 90° flexion, 0° rotation, and 0° adduction were used for the following reasons: (1) most injuries are secondary to dashboard-type accidents, which occur with the hip flexed approximately 90°; (2) an examination at 90° would reveal more potentially unstable hips than at 30°; and (3) patients need to be stable at 90° to perform daily activities, such as sitting and tying shoes.

The AFI, which describes the percentage of remaining intact posterior acetabulum from a CT scan, is a measurement to help determine hip stability in posterior fracture dislocations (Epstein Types I–IV). Intermediate AFIs include both stable and unstable fractures, and theoretically this overlap zone should be very narrow. Reasons for this overlap include the location of the fracture in the posterior wall, which may invovle a more superior portion of the acetabulum and therefore may be more stable than the same size fracture located directly posterior. The small normal anatomic variations in acetabular anteversion also help explain why some patients are stable and others are unstable, despite having the same AFI on the roentgenogram.

The role of CT for complete evaluation of posterior fracture dislocations of the hip has been described. The CT scan is used to make reproducible measurements because of its accuracy and availability. These measurements of the posterior acetabulum were used for calculation of the percentage of remaining intact posterior acetabulum, the AFI. Potential errors in making measurements on roentgenograms depend on: (1) ability to select the proper CT sections for the measurements; (2) appropriate use of the template in determining the center of the acetabular arc; and (3) errors in accurately marking the roentgenogram. These errors were minimized in this study because all measurements were done consistently and accurately by one examiner.

Abnormal anatomic variation of the acetabulum was not encountered in the 31 patients in this series. Previous acetabular fractures or congenital deformities would complicate the assessment of these measurements. Therefore, the conclusions drawn from this study may not apply to patients with these deformities.

It is because of the complexity in measurement of the AFI (which makes it clinically impractical) that the ApAFI was developed. Only a ruler is needed for a straight line measurement of the remaining intact posterior acetabulum. The ApAFI measurement is not as accurate as the AFI, but it is easy and has clinical application. Because measurement of the ApAFI is the practical method of calculating the percentage of intact remaining posterior acetabulum, it was also used to develop the Relative Risk Analysis, which provides the probability of hip stability on any given posterior acetabular fracture dislocation, based on the ApAFI. This analysis is limited by the relatively small number of patients in the stable and unstable groups; however, the linear regression line in Figure 9 may be used reliably as a prognostic tool.

Seventy percent of the unstable hips showed femoral head posterior subluxation greater than 0.5 mm, as opposed to none of the stable hips. This is significant since all of the patients were lying supine in the CT scanner with the hips in an extended position. Posterior subluxation in an extended position is diagnostic of hip instability. The question of hip stability still arises when,

after closed reduction, the CT scan reveals a variable size fracture of the posterior wall and no intraarticular fragments. How large should the posterior wall fragment be before the hip becomes unstable and requires open reduction and internal fixation? This article specifically addresses the amount of remaining posterior acetabulum, measured on the CT scan, and its correlation to hip stability.

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