

The Value of the Tip-Apex Distance in Predicting Failure of Fixation of Peritrochanteric Fractures of the Hip*

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ABSTRACT: Failure of fixation of peritrochanteric fractures that have been treated with a fixed-angle sliding hip-screw device is frequently related to the position of the lag screw in the femoral head. A simple measurement has been developed to describe the position of the screw. This measurement, the tip-apex distance, is the sum of the distance from the tip of the lag screw to the apex of the femoral head on an anteroposterior radiograph and this distance on a lateral radiograph, after controlling for magnification. To determine the value of this measurement in the prediction of so-called cutout of the lag screw, 198 peritrochanteric fractures (193 patients) were studied. The minimum duration of follow-up was three months (average, thirteen months), during which period all of the fractures either healed or had failure of the fixation. Of the nineteen failures that were identified, sixteen were due to the device cutting out of the femoral head.

The average tip-apex distance was twenty-four millimeters (range, nine to sixty-three millimeters) for the successfully treated fractures compared with thirty-eight millimeters (range, twenty-eight to forty-eight millimeters) for those in which the screw cut out ($p = 0.0001$). None of the 120 screws with a tip-apex distance of twenty-five millimeters or less cut out, but there was a very strong statistical relationship between an increasing tip-apex distance and the rate of cutout, regardless of all other variables related to the fracture. An increasing age of the patient, an unstable fracture, a poor reduction, and use of a high-angle (150-degree) side-plate were also associated with a significantly increased risk of failure due to cutout. With use of a

logistic regression model, the tip-apex distance was shown to be a stronger predictor of cutout ($p < 0.0001$) than any other variable, and the probability of the screw cutting out was calculated for any given tip-apex distance.

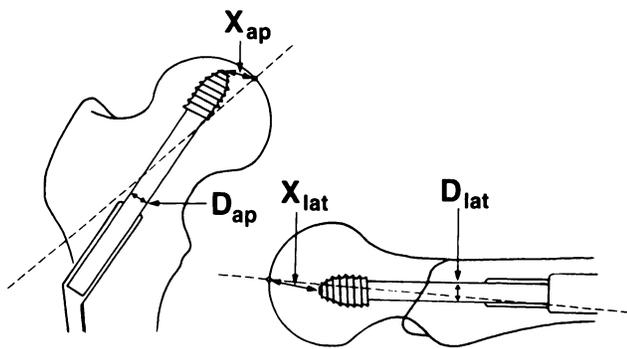
The failure of fixation of peritrochanteric fractures of the hip exacts a major cost from both the patient and the health-care system¹⁶. Since the mid-1970's, the fixed-angle sliding hip-screw has been a favored treatment for these injuries because it allows controlled impaction of the fracture in order to reach a position of stability and yet maintains a constant neck-shaft angle. Nonetheless, the rate of mechanical failure of this device has been reported to be as high as 16 to 23 per cent^{2,30,34}. The usual mechanism of failure has been the collapse of the neck-shaft angle into varus, leading to extrusion, or so-called cutout, of the screw from the femoral head. Many attempts have been made to identify and quantify the variables that affect this type of failure of fixation. The age of the patient, the quality of the bone, the pattern of the fracture, the stability of the reduction, the angle of the implant, and the position of the lag screw within the femoral head have all been related to this mechanism of failure, but there has been no clear consensus as to the interrelationships or relative importance of each factor. Most authors have recognized the importance of accurate placement of the screw, but the methods that have been described to evaluate the position of the screw have tended to have little predictive value or have proved exceedingly cumbersome in the clinical setting.

We developed a new and simple technique to describe the placement of the lag screw within the femoral head. With this measurement, known as the tip-apex distance, a single number is generated to summarize the position and depth of the lag screw on both the anteroposterior and lateral radiographs. We compared our technique with other methods of describing the location of the screw, and we compared the measurement with other variables that have been reported to be associated with failure due to cutout. The purpose of the current paper is to introduce the concept of the tip-apex distance and to demonstrate its clinical usefulness as a strong predictor of cutout of the screw used for proximal fixation of peritrochanteric fractures of the hip.

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$$\text{TAD} = \left(X_{\text{ap}} \times \frac{D_{\text{true}}}{D_{\text{ap}}} \right) + \left(X_{\text{lat}} \times \frac{D_{\text{true}}}{D_{\text{lat}}} \right)$$

FIG. 1

Technique for calculating the tip-apex distance (TAD). For clarity, a peripherally placed screw is depicted in the anteroposterior (ap) view and a shallowly placed screw is depicted in the lateral (lat) view. (D_{true} = known diameter of the lag screw) (see text).

Materials and Methods

To be included in the study, a patient had to have been treated with a fixed-angle sliding hip-screw for a peritrochanteric fracture of the hip, complete radiographic and clinical data had to be available, and the patient had to have been followed for at least three months or to have had a documented early failure of fixation. From the records on 336 consecutively treated fractures of the hip, we identified 198 fractures (193 patients) that met these criteria. The duration of follow-up averaged thirteen months (range, three to forty-eight months).

The clinical data that were collected included the patient's sex, age, and medical status (as summarized by the rating of the American Society of Anesthesiologists¹ that was recorded in the preoperative medical assessment). There were 141 women and fifty-two men in the study group. The average age was seventy-seven years (seventy-one years [range, twenty to 100 years] for the men and seventy-nine years [range, nineteen to ninety-eight years] for the women).

The fracture patterns were classified according to the system of Evans as modified by Kyle et al.¹⁷ and the system of Müller et al.²⁵. Eighty-nine (45 per cent) of the fractures were classified as stable and 109 (55 per cent) were classified as unstable. The technical quality of the radiographs and the positioning of the patient were too variable to allow reliable quantification of osteoporosis with use of the method of Singh et al.³¹.

The type of implant and its neck-shaft angle were recorded. Fixation was accomplished with 142 screw and side-plate devices and fifty-six intramedullary devices. The side-plates included the Ambi (Richards, Memphis, Tennessee), the KeyFree (Zimmer, Warsaw, Indiana), and the DHS (Synthes USA, Paoli, Pennsylvania) devices. The intramedullary devices were either Gamma nails (Howmedica, Rutherford, New Jersey) or

intramedullary hip-screws (Richards). The angle of the side-plate was 130 degrees (one fracture), 135 degrees (forty-nine fractures), 140 degrees (thirty-four fractures), 145 degrees (thirty-four fractures), or 150 degrees (twenty-four fractures). The angle of the intramedullary implant was 125 degrees (three fractures), 130 degrees (twenty-two fractures), 135 degrees (twenty-six fractures), or 140 degrees (one fracture). The angle was not recorded for four of the intramedullary devices.

The tip-apex distance was used to describe the position of the screw. The tip-apex distance is defined as the sum of the distance, in millimeters, from the tip of the lag screw to the apex of the femoral head, as measured on an anteroposterior radiograph and that distance as measured on a lateral radiograph, after correction has been made for magnification. The apex of the femoral head is defined as the point of intersection between the subchondral bone and a line in the center of and parallel to the femoral neck. For the purpose of this study, the immediate postoperative radiographs were used to measure the tip-apex distance. The amount of radiographic magnification was determined precisely by dividing the diameter of the projected shaft of the screw as seen on the radiograph by its known diameter (8.0 to 12.0 millimeters, depending on the manufacturer), and correction was achieved by multiplying the measurement of the distance by this factor (Fig. 1).

Although the tip-apex distance was not measured intraoperatively in this study, it can easily be estimated during an operation with use of an image intensifier, after placement of the guide-pin but before the screw has been drilled and inserted. Good anteroposterior and lateral views on the image intensifier are required for the surgeon to be able to identify, with confidence, the apex of the femoral head and the distance between it and the tip of the guide-pin. If desired, the amount of fluoroscopic magnification can be assessed by comparing the apparent length (or diameter) of the guide-pin's threaded tip with its known size. Generally, if the distance from the guide-pin to the apex appears to be less than one to 1.5 times the length of the threaded portion of the pin on both views, the tip-apex distance will be less than twenty-five millimeters.

The location of the screw was also recorded according to the zones described by Cleveland et al.⁷ and subsequently used by Kyle et al.¹⁷. With this method, the femoral head is divided into superior, central, and inferior thirds on the anteroposterior radiograph and into anterior, central, and posterior thirds on the lateral radiograph, thus making a total of nine separate zones in which the screw can be located.

The quality of the reduction of the fracture that was achieved intraoperatively was assessed on the basis of displacement and alignment of the fracture as seen on the immediate postoperative radiographs. The reduction was categorized as good, acceptable, or poor. For a reduction to be considered good, there had to be normal

or slight valgus alignment on the anteroposterior radiograph, less than 20 degrees of angulation on the lateral radiograph²⁰, and no more than four millimeters of displacement of any fragment. To be considered acceptable, a reduction had to meet the criterion of a good reduction with respect to either alignment or displacement, but not both. A poor reduction met neither criterion. The reduction of ninety-one fractures (46 per cent) was judged to be good; that of seventy-eight (39 per cent), acceptable; and that of twenty-nine (15 per cent), poor. Of the stable fractures, fifty-six had a good reduction; thirty, an acceptable reduction; and three, a poor reduction. In contrast, there were thirty-five good, forty-eight acceptable, and twenty-six poor reductions of the unstable fractures.

The 193 patients were followed clinically and radiographically until either the fixation had failed or the fracture had united. The radiographs were assessed for impaction of the fracture as well as for telescoping, migration, and cutout of the screw. However, given the variability of the positioning of the patients and of the quality of the radiographs, as well as the relative lack of clinical importance of isolated migration, only cutout of the screw and union of the fracture were considered as end points.

The effect of both interobserver and intraobserver variability on the tip-apex distance was examined to evaluate the reproducibility of the measurement. Additionally, we examined the geometrical relationship between the tip-apex distance, which is a summation of measurements on radiographs made in two projections (two-dimensional), and the actual distance within the sphere of the femoral head from the tip of the screw to the apex (three-dimensional).

The statistical techniques that were used included the Student t test for interval data and the multiple contingency analysis (chi-square test) for categorical data. Bivariate and multivariate logistic regression was used to investigate the interactions among the independent variables and their ability to predict cutout of the screw. A probability of 0.05 or less for a type-I error was considered significant.

Results

The treatment of nineteen (10 per cent) of the 198 fractures failed. Sixteen of the failures were due to the screw cutting out of the femoral head. The rate of cutout in all 198 femoral heads was 8 per cent. The other three causes of failure included non-union with a broken side-plate, deep infection, and complete collapse of the hip-screw that necessitated revision to a hemiarthroplasty early in the postoperative period. Fourteen of the sixteen failures that were due to cutout of the screw occurred within twelve weeks after the operation. The two remaining failures were not identified until the sixth postoperative month, but neither patient had been evaluated since the time of discharge from the acute-care

hospital, and it was not clear exactly when the cutout had occurred. No screw was known to have cut out after the third postoperative month.

Variables Associated with the Screw Cutting Out of the Femoral Head

The tip-apex distance averaged twenty-five millimeters (range, nine to sixty-three millimeters) for the 198 fractures. In the sixteen femoral heads from which the screw had cut out, it averaged thirty-eight millimeters (range, twenty-eight to forty-eight millimeters), compared with twenty-four millimeters (range, nine to sixty-three millimeters) in those from which the screw had not cut out. This difference between the two groups was significant ($p = 0.0001$, Student t test). More importantly, there was a direct relationship between an increased tip-apex distance and an increased risk of the screw cutting out of the femoral head. None of the 120 screws with a tip-apex distance of twenty-five millimeters or less cut out. Although a screw with a tip-apex distance of twenty-eight millimeters did cut out, the rate of cutout for the 150 screws that had a tip-apex distance of thirty millimeters or less was only 2 per cent (three), compared with 27 per cent (thirteen) of the forty-eight screws with a tip-apex distance of more than thirty millimeters. Of the twenty-five screws with a tip-apex distance of more than thirty-five millimeters, nine (36 per cent) cut out, compared with six of the ten screws with a tip-apex distance of forty-five millimeters or more (Fig. 2).

The patients in whom the screw cut out of the femoral head had an average age of eighty-five years (range, sixty-seven to ninety-five years), nine years older than the average age of the patients in whom the fracture successfully healed (average age, seventy-six years; range, nineteen to 100 years). This difference between the two groups was significant ($p = 0.02$, Student t test). The sex of the patient had no significant effect on the rate of cutout of the screw ($p = 0.42$,

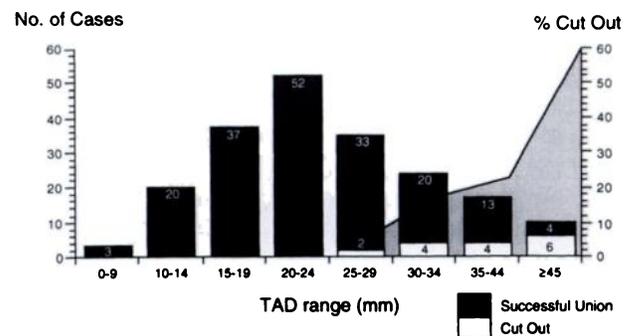


FIG. 2

Bar graph showing the tip-apex distance (TAD) for all 198 fractures. The average tip-apex distance was twenty-four millimeters for the fractures that were not associated with cutout, compared with thirty-eight millimeters for the fractures that had failure of the fixation because of cutout of the screw. The shaded area in the background shows the rate of cutout.

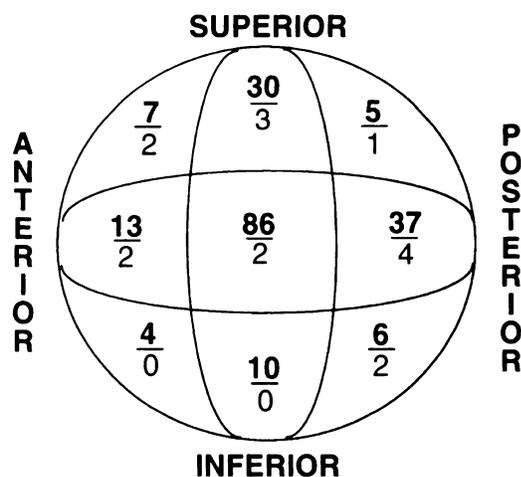


FIG. 3

The distribution, by zone, of the 198 screws and of the sixteen screws that cut out. The total number of screws in each zone is represented by the numerator, and the number of screws that cut out in each zone is represented by the denominator.

chi-square test), and neither did the patient's medical status¹ ($p = 0.60$, multiple contingency analysis).

Of the sixteen screws that cut out, two had been used to fix a stable fracture and fourteen, an unstable fracture. The difference in the rate of cutout between the stable and unstable fractures was significant ($p = 0.0007$, chi-square test).

Of the ninety-one good reductions, five (5 per cent) (four of an unstable fracture and one of a stable fracture) were followed by cutout of the screw; of the seventy-eight acceptable reductions, six (8 per cent) (five of an unstable fracture and one of a stable fracture) were followed by cutout; and of the twenty-nine poor reductions, five (17 per cent) (all of an unstable fracture) were followed by cutout. The different rates of cutout in these three groups did not reach significance according to multiple contingency analysis ($p = 0.13$), but a significant increase was noted in the group that had had a poor reduction compared with the group that had had a good reduction ($p = 0.04$, chi-square test).

Ten (7 per cent) of the 142 fractures that had been treated with a screw and side-plate device and six (11 per cent) of the fifty-six that had been treated with an intramedullary device were associated with cutout of the screw. This difference was not significant ($p = 0.57$, chi-square test). Of the ten angled side-plates that were associated with cutout of the screw, five were among the twenty-four with a barrel angle of 150 degrees. This 21 per cent rate of cutout associated with the devices with an angle of 150 degrees was significantly higher than the 4 per cent rate associated with the remaining 118 side-plates ($p = 0.02$, chi-square test).

As evaluated according to the zones described by Cleveland et al.⁷ and used by Kyle et al.¹⁷, lag screws were found to have been placed in all nine possible locations within the femoral head, and screws cut out from seven of the nine zones (Fig. 3). Screws were

most frequently placed in the center-center zone (43 per cent) and least frequently, in the anterior-inferior zone (2 per cent). The highest rates of cutout occurred in the posterior-inferior zone (two of six screws) and in the anterior-superior zone (two of seven screws). The rate of cutout in either of these two peripheral zones was significantly higher than the rate in the center zone ($p = 0.01$ and $p = 0.02$, respectively; chi-square test). However, the placement of screws in any of the other six zones — that is, the placement of 50 per cent of all screws — had no predictive significance with respect to cutout.

We employed logistical regression to test the effects of the variables on each other as well as the strength of each variable's relationship to cutout of the screw. When variables were tested in isolation, with cutout of the screw as the dependent variable (bivariate logistic regression), an increased tip-apex distance was found to be the strongest ($p = 0.0001$) but not the only predictor of failure due to cutout. An increasing age of the patient ($p = 0.02$), an unstable fracture pattern ($p = 0.02$), a 150-degree side-plate ($p = 0.02$), and placement of the screw in the posterior-inferior zone ($p = 0.04$) were also each shown to be predictive. Placement of the screw in the anterior-superior zone of the femoral head did not reach significance ($p = 0.07$) for cutout, whereas placement in the center-center zone was a negative predictor ($p = 0.02$). Poor reductions did not achieve predictive significance ($p = 0.058$) in a bivariate model. When we looked at an increasing valgus angle of the side-plate (130 to 150 degrees) and not just at use of a 150-degree side-plate as a predictor of cutout, no relationship was found ($p = 0.28$).

Bivariate logistic regression also allowed calculation of the probability of a cutout for any given tip-apex distance (Fig. 4).

With use of a multivariate model, when cutout of the screw was regressed against both the tip-apex distance and the zone in which the screw had been placed, none of the zones had any predictive significance for cutout, whereas the tip-apex distance remained a strong predictor ($p = 0.0001$). In other words, by controlling for

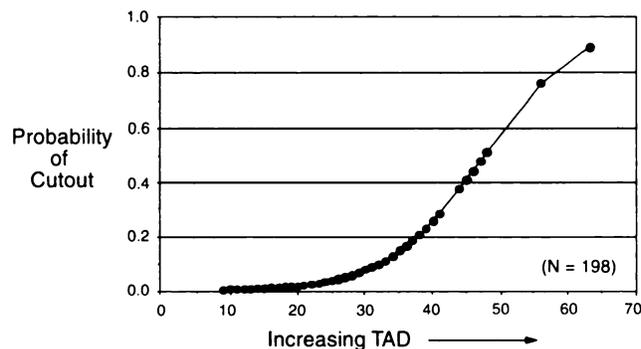


FIG. 4

Graph showing the probability of cutout as a function of the tip-apex distance (TAD) (in millimeters) for the 198 fractures.

the tip-apex distance, even placement of the screw in the posterior-inferior or center-center position did not predict for (or against) cutout. In all multivariate environments, the significance of the tip-apex distance remained high and was least affected by the addition or deletion of other variables. In the multivariate model that included all variables, the tip-apex distance ($p = 0.0002$), the patient's age ($p = 0.002$), instability of the fracture ($p = 0.03$), and a 150-degree side-plate ($p = 0.005$) were significant independent predictors, but the quality of the reduction of the fracture and the location of the screw according to zone were not significant ($p = 0.6$ for both).

Analysis of the Measurement of the Tip-Apex Distance

To assess the reproducibility of the measurement of the tip-apex distance, both intraobserver and interobserver variability was studied. Each of us independently determined the tip-apex distance for fifty-five fractures (110 radiographs; 220 measurements), and the results were compared. The standard deviation among us averaged 1.7 millimeters (10 per cent), with a range of 0.3 to 5.1 millimeters. We then remeasured the radiographs two to four months after the original evaluations, and the results were compared with the previous measurements. The intraobserver standard deviation at that time averaged 1.2 millimeters (7 per cent), with a range of zero to 5.7 millimeters.

The tip-apex distance represents the summation of measurements on radiographs made in two orthogonal projections, not the physical distance from the tip of the screw to the apex of the three-dimensional femoral head. This so-called true distance can be determined geometrically (see Appendix). This distance was calculated for fifty-five fractures and compared with the tip-apex distance for each fracture. The true distance divided by the tip-apex-distance ratio averaged 0.59 (range, 0.49 to 0.82). The correlation coefficient was 0.97.

Discussion

The importance of the position of the screw within the femoral head has been recognized since the earliest reports of clinical results associated with use of the sliding hip-screw. Schumpelick and Jantzen²⁸ concluded, from their review of the results for the first twenty-eight fractures that they had treated with this device, that the screw should run along the inferior portion of the femoral neck, remain low in the head, and appear well centered on the lateral radiograph, and that the tip of the screw should be three to five millimeters from the articular surface. Clawson⁶ recommended deep placement, to within six millimeters of the subchondral bone. Neither of these reports included data on variance of the position of the implant to support the authors' recommendations.

Numerous subsequent reports have contained com-

ments on the position of the screw, with most authors having favored a central position^{3,4,8,11,12,14,17,19,21,23,24,29,33,34} or an inferior position^{7,9,13,15,22,26,27,32,35}. Biomechanical studies have further supported the use of these positions^{5,10}, and there is nearly unanimous agreement that the anterior-superior location is to be avoided.

Despite a general agreement on the importance of proper positioning of the screw, the methods that have been advocated for determining the location of the screw have been inexact and cumbersome. Mulholland and Gunn²⁴, Doherty and Lyden¹¹, and Greider and Horowitz¹⁴ described the location of the screw relative to its distance (as measured in screw diameters) from the central axis of the femoral neck and head on both anteroposterior and lateral radiographs. They judged the depth of penetration of the screw according to the number of turns that would be necessary to advance the screw into the joint. This method allowed for nine locations and two continuous-depth readings. The system of nine zones used by Kyle et al.¹⁷ did not account specifically for the depth of penetration of the screw. Thomas³² added more peripheral zones to the system of Kyle et al. to account for depth and described seventeen different regions of the femoral head. In 1990, Larsson et al.²⁰ took into account the direction and depth of the screw by bisecting the femoral head by perpendicular axes and then dividing the resulting quadrants into eleven zones on both radiographs. Bridle et al.³ used similar axes but divided each radiograph into nine areas. Recently, Parker²⁶ used a ratio technique to define the direction (but not the depth) of the lag screw on both radiographs.

The classifications used by Mulholland and Gunn²⁴ and by Kyle et al.¹⁷ allowed these authors to conclude that a central, deep position of the screw on both radiographs was optimum. Kyle et al. presented data on seventy-four unstable fractures that had been treated with sliding nails, but neither paper offered any statistical support for the authors' conclusions. Summing the zones used by Kyle et al. into columns, Davis et al.⁸ found a significantly increased risk of cutout when the screw was placed posteriorly compared with centrally. They noted, however, that cutouts occurred in all zones in which at least two devices had been implanted. Parker²⁶ compared a group of twenty-five selected femoral heads from which the screw had cut out with a group of 200 in which the fracture had healed, with use of the ratio technique mentioned earlier; he noted a significant tendency for posteriorly or superiorly positioned screws to cut out. It was unknown if the two groups were comparable with respect to variables such as the stability of the fractures or the ages of the patients, and the author did not give the actual rate of cutout for any particular position of the implant.

Our study of tip-apex distances supports previous recommendations that central, deep placement of the screw is optimum, and it clarifies the association be-

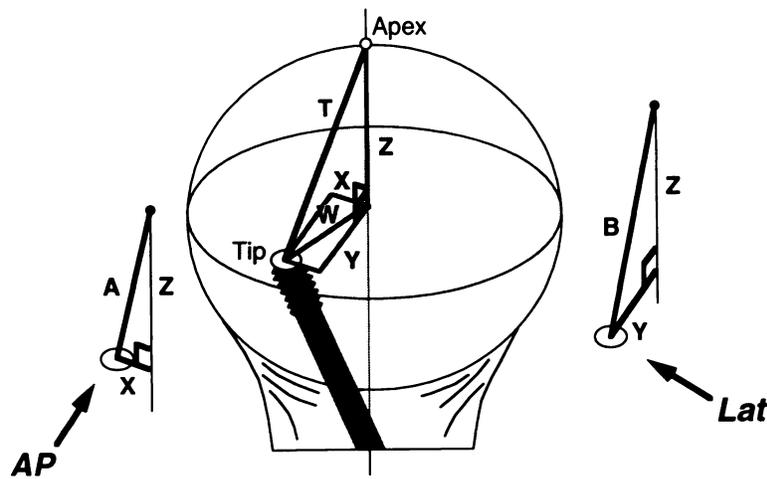


FIG. 5

The relationship between the measurement of the tip-apex distance and the calculated true distance. T = true distance. A = tip-apex distance as recorded from the anteroposterior radiograph, and B = tip-apex distance as recorded from the lateral radiograph (see Appendix).

tween the position of the screw and the likelihood of its cutting out of the femoral head. With use of the measurement, the division of the femoral head into arbitrary zones is avoided but both the location and the depth of penetration of the screw are taken into account. By allowing a combination of quantitative measurements on both radiographs, the tip-apex distance enables the position of the screw to be summarized with a single value on a ratio scale.

In previous reports^{18,19,22}, patients have been grouped according to certain variables in an attempt to identify those who might be at increased risk for cutout of the screw. The use of bivariate and multivariate regression in the current study allowed us to confirm significant relationships between certain variables (the patient's age, the fracture pattern, the quality of the reduction, the use of a 150-degree-angle side-plate, and the position of the screw) and the risk of cutout, as well as to demonstrate the relative strengths of these relationships. Furthermore, use of these statistical methods showed that the position of the screw as determined by the tip-apex distance was the strongest predictor of cutout among the variables that were studied.

The current study might be criticized for the relatively high percentage of fractures that were excluded and the short minimum duration of follow-up of three months. Of the 138 fractures that were excluded because of inadequate documentation, eighty had complete perioperative data but follow-up information was lacking. There was no significant difference between this group that did not have adequate follow-up and the study group with respect to the stability of the fracture ($p = 0.25$) or the quality of the reduction ($p = 0.35$), and the average tip-apex distance of 25.3 millimeters was nearly identical to that of the study group ($p = 0.76$). Therefore, it appears that the study group was representative of the patients who were managed for a peritrochanteric fracture of the hip at our institution.

We chose three months as the minimum follow-up period for two reasons. Numerous authors have used three months as an end point or have noted that all cutouts of the screw have occurred within three months after the operation^{18,19,22,27}. Equally important, however, is the fact that the cutout rate of 8 per cent in the current study is only one-half to one-third the mortality rate for this group of patients in the first year after the fracture. A longer minimum duration of follow-up would strongly bias the results by excluding many patients who die with a well healed fracture.

In conclusion, we believe that this simple, reproducible method is more helpful than previous attempts to describe the location of the screw. The routine intraoperative estimation of the tip-apex distance can increase the surgeon's awareness of the probability of cutout of the screw and can help to guide operative decision-making. Regardless of the zone in which the guide-pin is placed, if the proposed position results in a tip-apex distance of greater than twenty-five millimeters, we recommend reconsideration of the reduction and redirection of the guide-pin.

Appendix

The so-called true distance (T) from the tip of the screw to the apex of the femoral head can be calculated with use of the anteroposterior and lateral radiographs (Fig. 5). Distance Z can be measured on either radiograph. Distance X can be measured on the anteroposterior radiograph by determining the length of the perpendicular from the axis (Z) to the tip of the screw. Distance Y can be measured similarly on the lateral radiograph.

With use of the Pythagorean theorem, $T = \sqrt{W^2 + Z^2}$ and $W = \sqrt{X^2 + Y^2}$; therefore, $T = \sqrt{X^2 + Y^2 + Z^2}$.

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