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Computer Aided Evaluation of Total Hip Prosthesis Stability

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Abstract. To obtain a stable total hip prosthesis it is of crucial importance that a prosthesis is well positioned and well orientated. In order to evaluate the position and orientation of the prosthesis one must determine at least four angles from the postoperative radiograph of the operated hip: inclination of the cup, anteversion of the cup, anteversion of the femoral part and valgus of the femoral part. If the measurement of these angles is carried out by a human himself, some mistakes caused by subjectivity of the person may frequently occur as well as the fact that this information is not useful intraoperative, since the measurement of these angles is usually done after the operation, when there is no way to correct the position and orientation of the prosthesis without another operation. The aim of this paper is to create an algorithm and a program for computer aided evaluation of total hip prosthesis stability in order to gain the most objective and sufficiently fast information which could greatly help the surgeon during the operation, before closing the wound, to decide whether the prosthesis is stable or not.

Key Words: total hip prosthesis, stability, measurement

1. Introduction

The foundation of a good clinical result after total hip arthroplasty is stability of the prosthesis which can only be obtained by accurate orientation of both the acetabular and femoral part of *total hip prosthesis* (THP). The existing methods of measuring the orientation of THP can not be used during the operation because they are neither precise nor fast enough, so these information can not help the surgeon to correct possible *malorientation* of the prosthetic components. Our idea was to create a program for *computer aided evaluation of the*

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orientation of THP which would be of great help to the surgeon when he or she needs it. And this is during the operation — and not after, when nothing except a second operation could be done to correct the possible mistakes.

2. Stability of THP

Instability of THP is one of the most common complications after a total hip arthroplasty. Dislocation of THP as a final form of instability of the prosthesis is the second among all complications after total hip arthroplasty (Woo and Morrey [14], 1982). It can prolong hospital stay, complicate rehabilitation, endanger the final result after a total hip arthroplasty and 22–55% of these patients require a revision operation (Ali Khan et al. [1], 1981). The incidence of dislocation of THP goes from 0,5% to 8%, average 2,7% (Lewinnek et al. [9], 1978). Fontes et al. [5], (1991), divided the dislocations of THP according to the direct cause of dislocation in two main groups:

- dislocations of THP caused by malposition and malorientation of THP
- dislocations of THP caused by inadequate soft tissue tension around the hip.

But according to our clinical experience (Miljkovic [11], 1996) the main cause of the dislocation of THP is malorientation of THP and/or malposition of THP.

3. Orientation of THP

The orientation of THP refers only to the direction of the prosthetic components in regard to the defined axes and planes (Fackler and Poss [4], 1980). Correct orientation of THP is crucial for a stable prosthesis [11]. Dorr et al. [2], 1983, showed that 23% of all dislocations of THP were caused by malorientation of the prosthesis, while Lewinnek et al. [9], 1978, considered this percentage to be higher, up to 33%. The highest limit of 50% of all dislocations of THP caused by malorientation of THP was stated by Coventry et al. [3], 1974.

3.1. Orientation of the acetabular part of THP

It is thought by many authors that the orientation of the acetabular part of THP is the most important factor for the stability of THP (Ritter [12], 1980). The orientation of the acetabular part of THP includes *acetabular inclination* and *acetabular anteversion.*

3.1.1. Acetabular inclination

Acetabular inclination is a two-dimensional (2D) measure of the acetabular orientation on plane films of the pelvis in the anteroposterior (a.p.) view. It is defined as the angle between a line through the long axis of the elliptical projection of the radioopaque outer wire cup ring or circumferential furrows in the plastic socket and the line through the lower margins of the ischial tuberosities or the inferior limits of both sacroiliac joints (Lindberg et al. [10], 1982). Generally regarded, it is a measure of how vertical the socket has been inserted. $40° \pm 10°$ is considered normal by Lewinnek et al. [9], 1978. An upper limit of 50° is stated by Ali Khan et al. [1], 1981, and of 55° by Dorr et al. [2], 1983, and Gore et al. [6], 1982. If the acetabular inclination is 60° or more, superior dislocation of THP may occur. On the other hand, if the acetabular inclination is lower than normal, which means that the socket is almost horizontal, there is a great risk of a posterior dislocation of THP (Harkess [7], 1992).

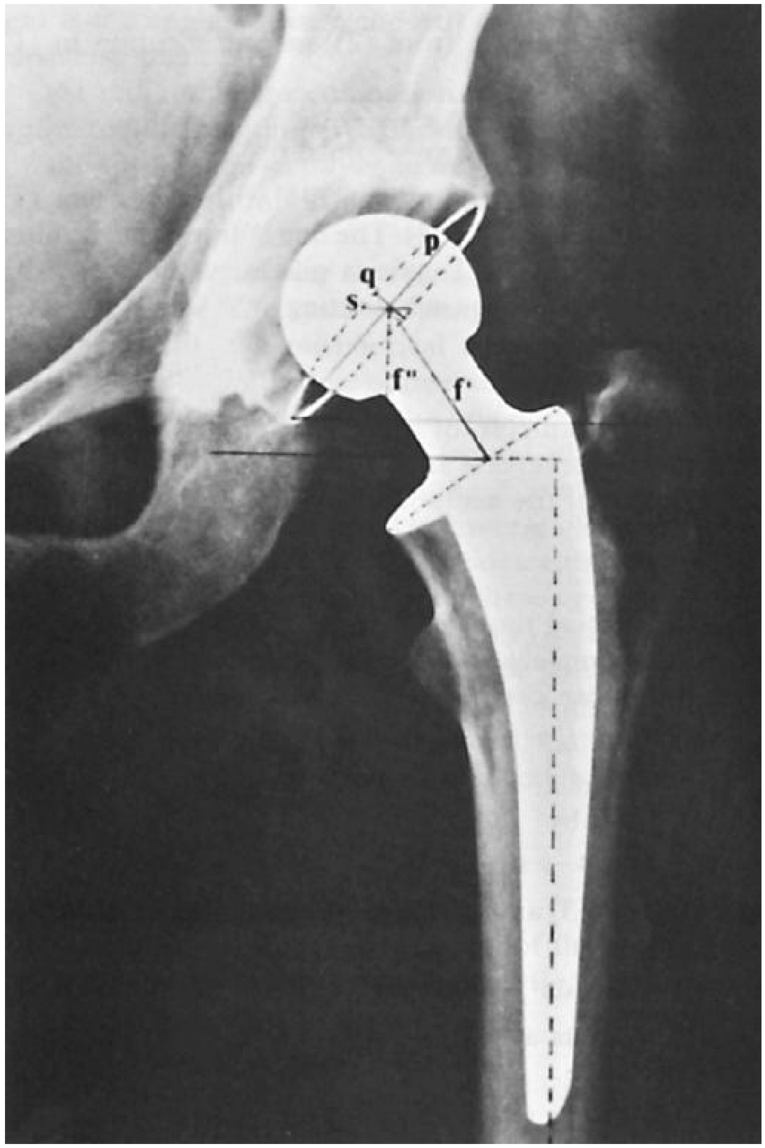


Figure 1: Anteroposterior radiograph of a total hip prosthesis on which all the lines needed for measurements and calculations have been drawn.

3.1.2. Acetabular anteversion

Although there has been a lot of confusion in the literature about the exact definition of the acetabular anteversion, most of the authors (Dorr et al. [2]) consider *planar anteversion* as the acetabular anteversion. Planar anteversion represents a measure of degree of anterior or posterior rotation of the cup opening around the long axis of the elliptical projection of the radioopaque outer wire cup ring on radiographs in a.p. view centred over the hip. Alternatively, if there is no marker wire, the same axis can be defined by the circumferential furrows in the plastic socket. Planar anteversion measures the rotation in a plane that is perpendicular to the long axis of the elliptical projection of the acetabular opening. But the most accurate way of measuring the acetabular anteversion is by computed tomography (CT). Lewinnek et al. [9], 1978, defined the normal range of acetabular anteversion as $15° \pm 10°$, Dorr et al. [2], 1983, as 0° to 30°, while Ali Khan et al. [1], 1981, considered any value exceeding 15° as abnormal. Fackler and Poss [4], 1980, defined the normal range of acetabular anteversion as absence of retroversion. If the value of the acetabular anteversion exceeds these normal ranges, anterior dislocation of THP may occur. On the other side, if there is no acetabular anteversion so the acetabular part of the prosthesis is in retroversion, posterior dislocation of THP will very likely occur.

3.2. Orientation of the femoral part of THP

The orientation of the femoral part of THP includes *femoral anteversion* and *valgus of the femoral part.*

3.2.1. Femoral anteversion

Woo and Morrey [14], 1982, considered femoral anteversion to be more difficult to measure than acetabular anteversion. According to Harkess [7], 1992, femoral anteversion can be defined as the angle between the axis of the femoral neck and the axis of the knee joint, observed in a coronal plane, while Visser and Konnings [13], 1981, define this angle, in total hip prosthesis, as the angle between the transcondylar plane and a plane including the axis of the femoral shaft and neck of the femoral component. There is a possibility to calculate the degree of femoral anteversion from the distance between the femoral axis and the rotational centre of the hip joint in the straight a.p. view and in the lateral view (Herrlin [8], 1988). The degree of femoral rotation around its long axis is measured and accounted for based on a radiograph in the lateral projection of the knee joint with the same position of the femur. But CT gives the most accurate measurements of the femoral anteversion. Harkess [7], 1992, defined the normal range of femoral anteversion as 5° to 10°, although upper limit of 15° is also acceptable. If the femoral anteversion exceeds 15° there is a great chance that anterior dislocation will happen. Similar to this, retroversion of the femoral part may lead to posterior dislocation.

3.2.2. Valgus of the femoral part of THP

The valgus of the femoral part is the angle between the axis of the neck and the transverse plane. Normal range of valgus is considered to be 35° to 50° (Visser and Konnings [13], 1981).

4. Existing Method of Measuring the Orientation of THP

A method for measuring angles after total hip arthroplasty (a study of acetabular cup and femoral component) was created by Visser and Konnings in [13], 1981. By this method acetabular anteversion, acetabular inclination, femoral anteversion and valgus of the femoral part can be measured. For the measurement and calculation of these angles it is necessary to make a postoperative a.p. radiograph of THP, to know the true length of the neck of the femoral part (F) and true diameter of the acetabular cup (Tac).

The following measurements are made from the radiograph of THP:

1. Mac — measured acetabular cup diameter (long axis (p) of the projected ellipse — Figs. 1 and 2
2. q — short axis of the projected ellipse — Figs. 1 and 2
3. s — the line of intersection of the ellipse with the Y-axis — Figs. 1 and 2

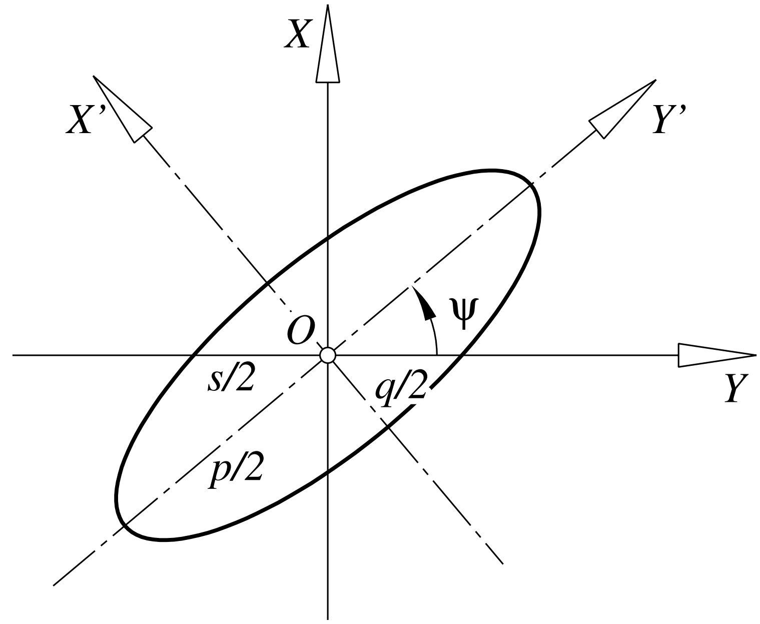


Figure 2: The XOY-system rotates through an angle ψ so that the long axis of the ellipse is lying upon the Y'-axis; p is the long axis, q the short axis of the ellipse and s the horizontal diameter of the ellipse (lying on the Y-axis)

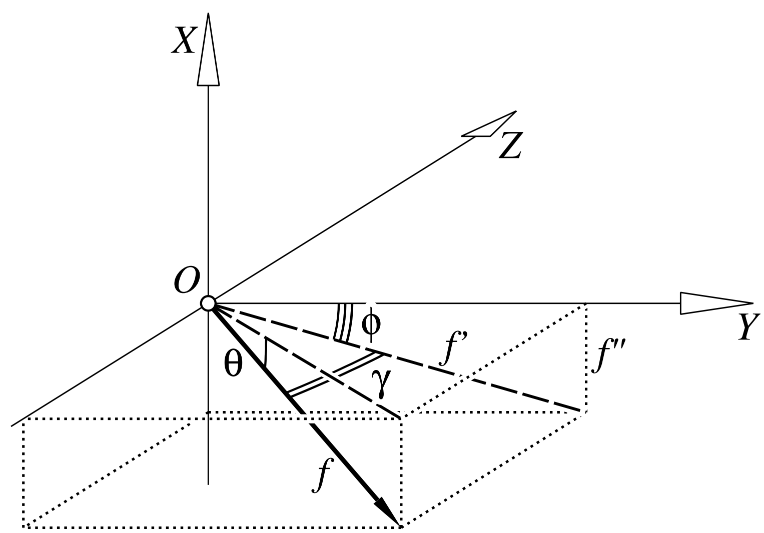


Figure 3: Projection of the axis for the corrected length of the femoral neck (f) into the XOY plane (f') measured on the radiograph. f'' is the projection of f', along the X- axis. The angle γ is the femoral neck anteversion, θ is the true valgus angle, and the ϕ apparent valgus angle of the femoral component.

4. f' — femoral neck length measured on the radiograph — Figs. 1 and 3
5. f'' — the X-component of the projection of this line on the XOY plane — Figs. 1 and 3
6. f — corrected length of femoral neck allowing the magnification of the radiograph
   $f = F \times \dfrac{Mac}{Tac}$.

Using these measurements the following angles can be calculated:

– acetabular anteversion $\alpha = \arcsin(s/d)$; $d = Mac$

– acetabular inclination $\beta = \arcsin(q/s)$

– femoral anteversion $\gamma = \arccos(f'/f)$

– valgus of femoral component $\theta = \arcsin(f''/f)$

The previous formulae have been derived under the following assumptions:

1. the centre of the sphere (THP, femoral head) is projected into the principal vanishing point;

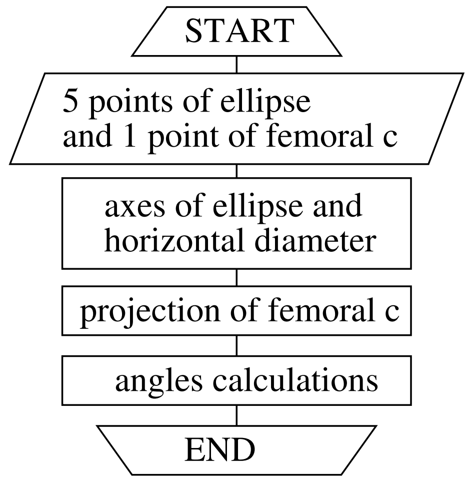
2. due to the distances: X-ray tube — sphere andsphere — X-ray film cassette, as well as properties of the X-ray tube with cones and aperture diaphragms, the perspective projection of sphere plane sections can be treated as orthogonal projection taking into account the appropriate magnification.

5. Computer Aided Method for Measuring Orientation of THP

Although the method described in previous section is easy to use and does not demand anything more than a pocket calculator, it is neither objective nor fast enough; so it can not be used during the operation. Our idea was to create an algorithm and program for computer aided measurement of the orientation of THP using an a.p. radiograph of THP taken during the operation. This program would provide the surgeon with the most objective measurement of the orientation of THP in only few minutes, so he or she could use this information during the operation for eventual correction of the malorientation of THP. In this way the *risk of instability* of THP would be greatly reduced.

The radioopaque outer wire cup ring, if perspective projection well done, is projected into an ellipse (cases of its either hyperbola or parabola projections, if occur will be treated as a malpositioned centre of projection or projection plane). Unfortunately, the radiograph does not show the whole ellipse because of properties of radiographic projection, but only the vicinity of great axis vertices (Fig. 1). The first step of the computer aided method is the recognition of the ellipse. Once the ellipse is recognized, all its parameters (measurements of axes and horizontal diameter) can be determined upon which significant angles α, β and γ can be calculated. The ellipse recognition comprises coefficient determination in a global coordinate system after mouse picking of five points of the ellipse visible part. Appropriate geometric transformations give the canonical equation of the ellipse, i.e., its great and small axis. One more point, picked by mouse at the appropriate marking point of the femoral part of THP, provides information necessary for calculation of the angle θ.

The computer application has been created in DELPHI 2.0. according to the following algorithm:



Program: THP Angles Determination

Input:

- five points of an ellipse: (x_i, y_i), $i = 1, \ldots, 5$
- one point of femoral component (a, b)
- true length of the neck of femoral part (F)
- true diameter of the acetabular cup (Tac)

Calculate:

- axes of the ellipse and horizontal diameter of the ellipse in the following steps:
  1. coefficient determination of the equation of the ellipse:

$$Ax^2 + 2A_1xy + A_2y^2 + 2A_3x + 2A_4y + A_5 = 0; \quad A \equiv 1$$

$$[A_{i,\, i=1\ldots5}]_{i\times1} = inv\left\{\left[2x_iy_i \quad y_i^2 \quad 2x_i \quad 2y_i \quad 1\,|_{i=1\ldots5}\ \right]_{i\times5}\right\}\left[-x_i^2|_{i=1\ldots5}\ \right]_{i\times1}$$

  2. centre of the ellipse

$$X_{ell} = \frac{A_1A_4 - A_2A_3}{A_2 - A_1^2}, \qquad Y_{ell} = \frac{A_1A_3 - A_4}{A_2 - A_1^2}$$

  3. axes of the ellipse:

$$p^2_{(L.A.)} = \frac{-2F_1}{1 + A^2 - \sqrt{(1-A)^2 + 4A_{12}}}, \quad q^2_{(S.A.)} = \frac{-2F_1}{1 + A^2 + \sqrt{(1-A)^2 + 4A_{12}}},$$

  where $F_1 = A_3X_{ell} + A_4Y_{ell} + A$

  4. horizontal diameter $s_{(H.D.)} = \sqrt{-F_1}$

- femoral component

$$f' = -\sqrt{(a - X_{ell})^2 + (b - Y_{ell})^2}, \quad f'' = X_{ell} - b, \quad f = F\frac{p}{Tac}$$

- angles $\alpha, \beta, \gamma, \theta$

Output: Fig. 4

End.

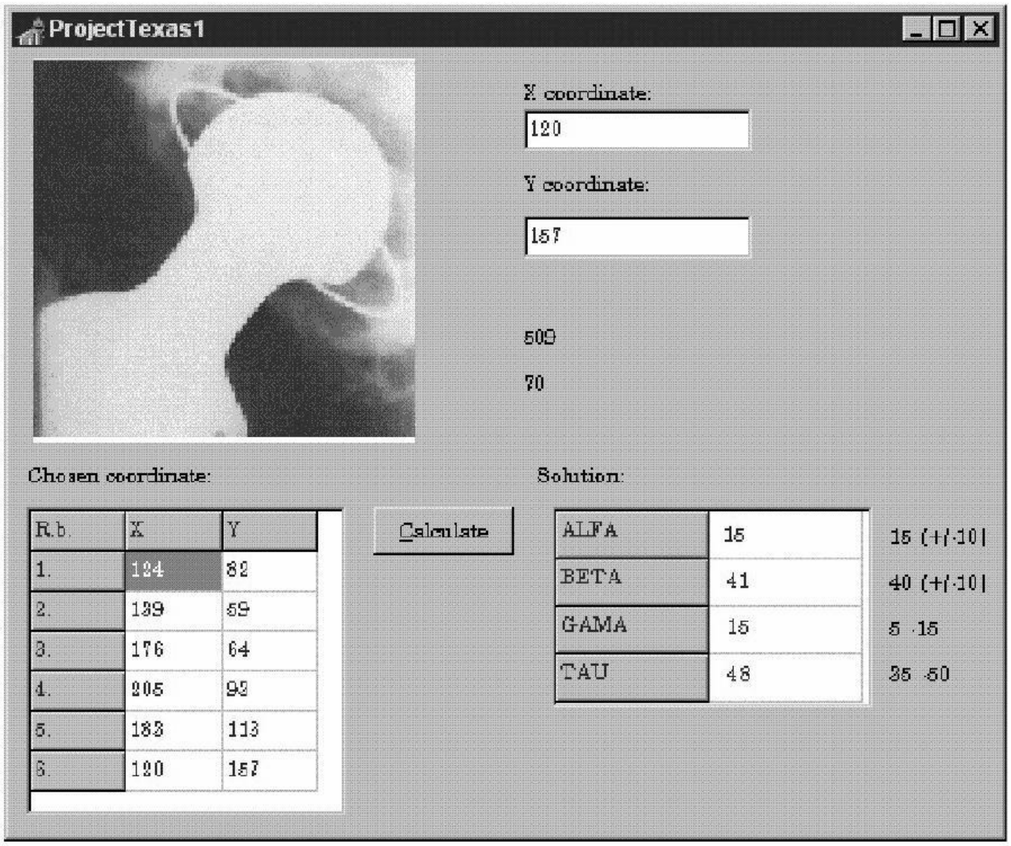


Figure 4: Window which is taken from Delphi 2.0

6. Conclusion

A computer aided method for the evaluation of THP stability was created. By this method it is possible to obtain accurate information about the orientation of THP during the operation, which is crucial for a stable prosthesis. This program could help to prevent or reduce the number of revision operations after total hip arthroplasty which are caused by instability of the prosthesis.

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