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# A Novel Method for Evaluating Position of the Stem of Hip Prostheses

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***Summary.*** **This study examined a novel method designed to assess the position of the stem of hip prostheses following Total Hip Arthroplasty (THA). Fifteen hip prostheses were scanned with a CT scanner in accordance with Gruen's zones. At the fourth zoning-layer of CT scanning, an XY coordinate system was attached to CT images. The origin of the coordinate system was placed at the center of the femoral medullary cavity. The X-axis was parallel to the posterior condylar axis of the distal femur; the arrowhead of the X-axis was directed toward the body's midline. Based on this observational methodology, stem tip position in the femoral medullary cavity was readily apparent in CT images when the CT window level ranged from 500 HU (hounsfield) to 600 HU and CT window width was 1500-2000 HU. These data -- including the center-to-center distance (distance between the center of the femoral medullary cavity and the center of the stem tip), the ratio of the center-to-center distance to the radius of the femoral medullary cavity and the quadrant value -- may be treated as the evaluative parameters of stem position in the femoral medullary cavity.**

**Key words**—hip prosthesis, tomography X-ray computed, evaluation studies.

## INTRODUCTION

Applications of total hip arthroplasty (THA) in cases involving osteoarthritis and rheumatoid arthritis and bipolar head prosthesis (BHP) in instances of femoral neck fracture are common. The development of artificial joints has achieved excellent clinical results characterized by the absence of pain, dislocation, aseptic loosening, etc. Physicians have realized the importance of the position of hip prostheses[1,2]. The position of the hip prosthesis in the femoral medullary cavity should meet the requirements of centralization regardless of prosthetic type (cemented or cementless). Centralization of the hip prosthesis stem denotes a situation in which the stem of the hip prosthesis is positioned at the center of the femoral medullary cavity in THA[1]. That is, the stem should be placed and maintained in a neutral position in the femoral cavity intraoperatively and postoperatively, respectively. Previous studies have demonstrated that centralization of the stem is an important factor in terms of preventing aseptic loosening and extension of the longevity and reliability of hip replacement[3]. Sound centralization of the femoral stem may reduce abnormal stress substantially via the even transmission and distribution of stress in the femoral stem. A suboptimal (thin) cement mantle at the medial diaphysis (Gruen zones 5 and 6) contributes to femoral component mechanical loosening; thus, centralization of the femoral component distal stem can ensure an adequate circumferential distal cement mantle[4]. The position of the stem greatly influences clinical outcome following THA or BHP; consequently, information regarding the position of the stem after surgery is essential.

However, the existing observational approach (e.g., standard X-ray) is deficient in terms of accuracy, intuition, and convenience. Although computed tomography (CT) is more accurate than standard X-ray[5],

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**Abbreviations**—BHP, bipolar head prosthesis; CT, computed tomography; HU, hounsfield; THA, total hip arthroplasty.

**Table 1.** Prosthesis profiles and measurement results

| Case no. | Prosthesis | Cementing | Center to center distance (mm) | Radius of femoral canal (mm) | Ratio | Position |
|---|---|---|---|---|---|---|
| 1 | Puwei (China) | + | 3.6 | 6.5 | 0.55 | d4 |
| 2 | Zimmer | + | 2 | 8.7 | 0.23 | d7 |
| 3 | Zhengtian (China) | − | 5.2 | 8.6 | 0.60 | d6 |
| 4 | Puwei (China) | + | 3.8 | 6.2 | 0.61 | d4 |
| 5 | Stryker | − | 2.3 | 5.5 | 0.42 | d8 |
| 6 | Puwei (China) | + | 6.1 | 10.1 | 0.60 | d4 |
| 7 | Zimmer | + | 4.4 | 7.5 | 0.59 | d7 |
| | Zimmer | + | 4.8 | 7.5 | 0.64 | d4 |
| 8 | Stryker | − | 3.6 | 6.4 | 0.56 | d4 |
| 9 | Puwei (China) | − | 6.4 | 10 | 0.64 | d4 |
| 10 | Zhengtian (China) | − | 3 | 5.4 | 0.56 | d4 |
| 11 | Zimmer | + | 6.9 | 9.9 | 0.70 | d6 |
| | Zimmer | + | 5.1 | 9.5 | 0.54 | d8 |
| 12 | Puwei (China) | − | 4.3 | 5.8 | 0.74 | d6 |
| 13 | Zhengtian (China) | + | 9.8 | 11.8 | 0.83 | d4 |
| Mean | | | 4.75 | 7.96 | 0.59 | |

the application of CT-based image analysis in patients undergoing THA is limited due to the presence of metal artifacts caused by metal components of the prosthesis[6].

Roentgen stereophotogrammetric analysis has demonstrated high accuracy[7]. However, this technique requires the attachment of markers to both the bone and prosthesis.

The current investigation describes a novel method for evaluation of the position of the stem of hip prostheses using a CT scanner.

## PATIENTS AND METHODS

Nine male and four female patients were scanned with a CT scanner (Somatom Plus B30B of SIEMENS, GERMANY) following THA or femoral head replacement. Eleven individuals were characterized by a single prosthesis and two subjects displayed bilateral prostheses. Eleven primary THAs, three revision THAs, and one BHP were included in this study. Cement, delivered via a cement gun, was employed in nine stems, and a distal centralizer was utilized in two stems (Table 1). Surgical techniques included a posterior approach in eight cases, a lateral approach in six cases, and an anterior approach in a single case. Average age of the patients at the time of operation was 40.5 years (range: 22-62 years). The time of postoperative CT scanning ranged from eight days to nine years.

Patients assumed a supine position with the feet placed together and toes pointing up. The lower extremities of these subjects were fixed with belts, ensuring that they remained stable during CT scanning. Based on Gruen's zones[8], these layers--including those levels of Gruen zones 1 to 7, Gruen zones 2 to 6, Gruen zones 3 to 5, Gruen zone 4 and distances 0.5 cm and 3 cm under the stem tip -- were respectively scanned (Fig. 1). At the fourth zoning-layer of CT scanning, an XY coordinate system was attached to CT images (Fig. 2). The origin of the coordinate system was placed at the center of the femoral medullary cavity. The X-axis was parallel to the posterior condylar axis of the distal femur (Fig. 3); the arrowhead was directed toward the body's midline in order to eliminate the difference in the direction between the right and left lower extremities.

In the clinic, a preliminary scan of the distal femur was necessary to define the direction of the X-axis, and other layers were subsequently scanned. In order to define the center of the femoral medullary cavity, two circles were drawn along the outline of the femoral medullary cavity: one was a maximum inscribed circle and the second was a minimum circumscribed circle. The midpoint of the connecting line between the centers of the inscribed and circumscribed circles was determined, this midpoint being defined as the center of the femoral medullary cavity.

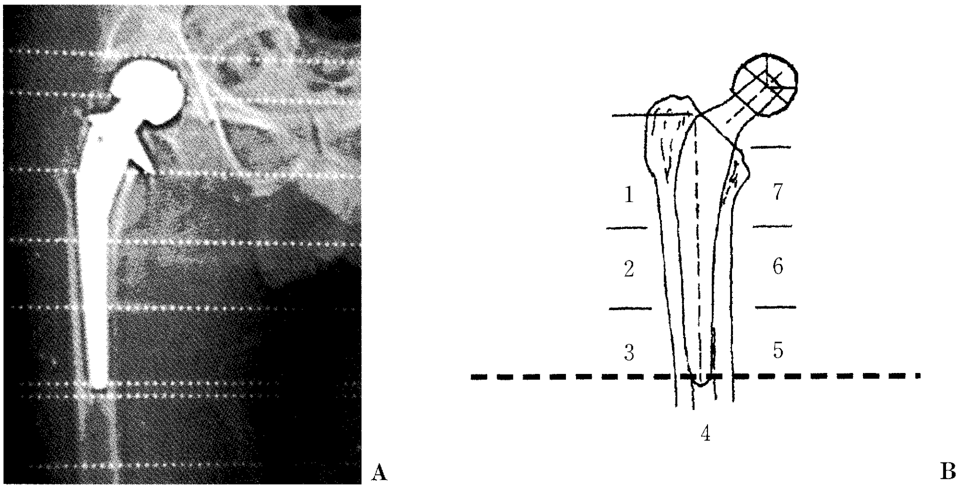


**Fig. 1.** Directional diagram of CT scanning: **A.** clinic CT image scanned according to Gruen's zones; **B.** schematic diagram of the fourth zoning-layer (*broken line*). At this point, the position of the stem is observed.

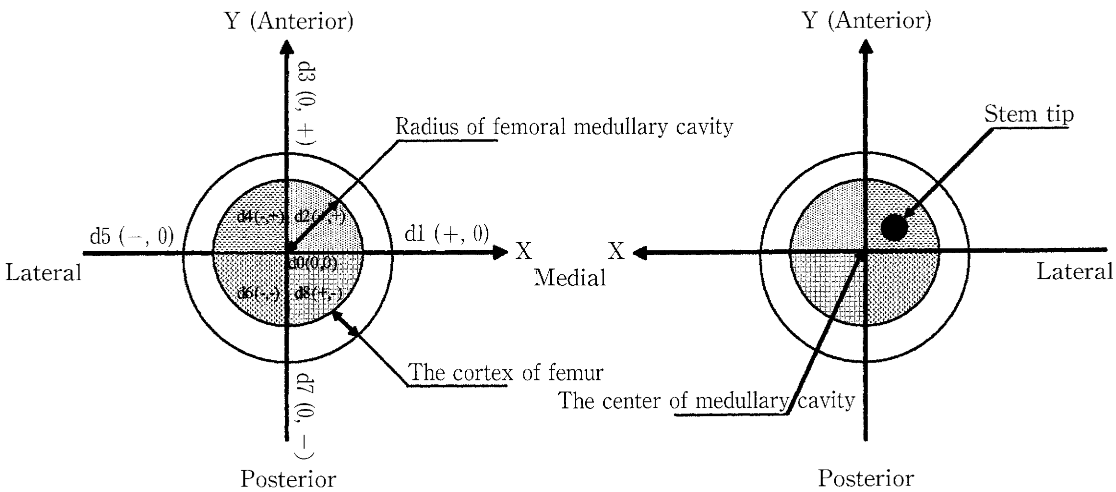


**Fig. 2.** Schematic diagram of the XY coordinate system at the fourth zoning-layer: The X-axis is pointed toward the body's midline, the black point represents the stem tip, and the two circles represent the cortex of the femur. The femoral cavity is divided into nine parts (d0 to d8).

The average radius of the inscribed and circumscribed circles was calculated, the average radius further functioning as the radius of the femoral medullary cavity (Fig. 4). Next, the following data were measured or observed at the level of the fourth zoning-layer on a CT monitor:

1. The center-to-center distance: the distance between the center of the femoral medullary cavity and the center of the stem tip.
2. The radius of the femoral medullary cavity (at the level of the fourth zoning-layer).
3. The ratio of the center-to-center distance to the radius of the femoral medullary cavity (the center-to-center distance/ the radius of the femoral medullary cavity).
4. The position of the stem tip within the femoral medullary cavity.

The position of the stem tip within the femoral medullary cavity was evaluated as follows:

A cross-section of the femoral medullary cavity at the level of the fourth zoning-layer was partitioned into nine components by the XY coordinate system.

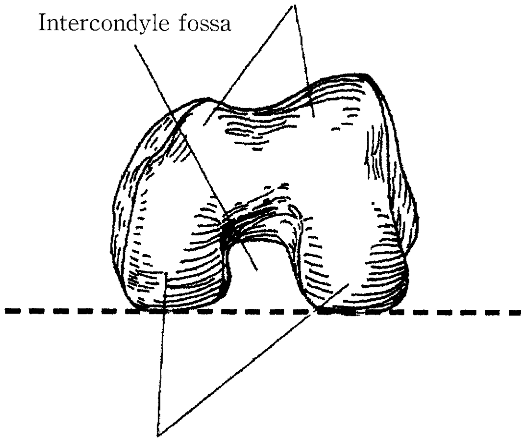


**Fig. 3.** Schematic diagram of the connecting line between the femoral posterior condyles. The X-axis is parallel to the connecting line.

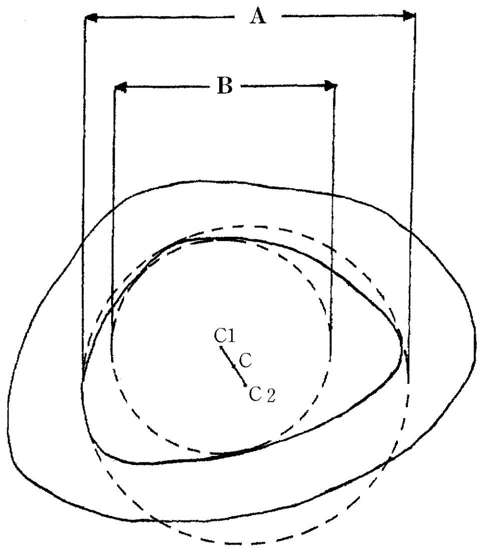


**Fig. 4.** Definition of the center of the femoral medullary cavity and measurement of the femoral medullary diameter. C1, center of the maximum inscribed circle; C2, center of the minimum circumscribed circle; C, midpoint of the connecting line between C1 and C2, i.e., center of the medullary cavity. A, diameter of the minimum circumscribed circle; B, diameter of the maximum inscribed circle. Accordingly, the average diameter of the medullary cavity is (A+B)/2, whereas the average radius is average diameter/2.

These components included the origin of the coordinate system (d0), the positive line aspect of the X-axis (d1), the area of the first quadrant (d2), the positive line aspect of the Y-axis (d3), the area of the second quadrant (d4), the negative line aspect of the X-axis (d5), the area of the third quadrant (d6), the negative line aspect of the Y-axis (d7), and the area of the fourth quadrant (d8). That is, the stem tip displayed nine types of centralized statuses in the femoral medullary cavity, ranging from d0 to d8 (Fig. 2).

d0 (0, 0): If the stem tip occurred at the point of origin of the coordinate system, the position of the stem tip was referred to as "d0". This definition indicates that the stem tip was positioned at the center of the femoral medullary cavity, which was the ideal centralized status of the stem tip.

d1 (+, 0): If the stem tip occurred at the positive line aspect of the X-axis, the position of the stem tip was referred to as "d1". This definition indicates that the stem tip tilted to the medial aspect of the femoral medullary cavity.

d2 (+, +): If the stem tip occurred in the area of the first quadrant, the position of the stem tip was referred to as "d2". This definition indicates that the stem tip tilted to the anterior-medial aspect of the femoral medullary cavity.

In a manner identical to the above:

d3 (0, +): The stem tip occurred at the positive line aspect of the Y-axis; this designation indicates that it tilted to the anterior aspect of the femoral medullary cavity.

d4 (−, +): The stem tip occurred in the area of the second quadrant; this designation indicates that it tilted to the anterior-lateral aspect of the femoral medullary cavity.

d5 (−, 0): The stem tip occurred at the negative line aspect of the X-axis; this designation indicates that it tilted to the lateral aspect of the femoral medullary cavity.

d6 (−, −): The stem tip occurred in the area of the third quadrant; this designation indicates that it tilted to the posterior-lateral aspect of the femoral medullary cavity.

d7 (0, −): The stem tip occurred at the negative line aspect of the Y-axis; this designation indicates that it tilted to the anterior aspect of the femoral medullary cavity.

d8 (+, −): The stem tip occurred in the area of the fourth quadrant; this designation indicates that it tilted to the posterior-medial aspect of the femoral medullary cavity.

The rationale for dividing the medullary cavity into nine parts by the coordinate system is as follows:

First, it is convenient to describe the actual position of the stem tip in the femoral medullary cavity and to contrast it with other positions. Secondly, with the aid of a coordinate system, the position of the stem tip may be presented by the value of the quadrant (quantification). Consequently, recording and processing of these data via computer is convenient as well as suitable for analysis of the correlation between the position of the stem tip and clinical outcome.

5. Metal artifact. Metal can result in a metal artifact during the course of CT scanning. In hip prostheses, the most prominent metal artifact was attributable to the acetabulum, which assumed a long fan shape.

The metal artifact weakened at the upper portion of the stem, exhibiting its greatest degree of weakening at the fourth zone of Gruen. The metal artifact could be eliminated by adjustment of the CT window level.

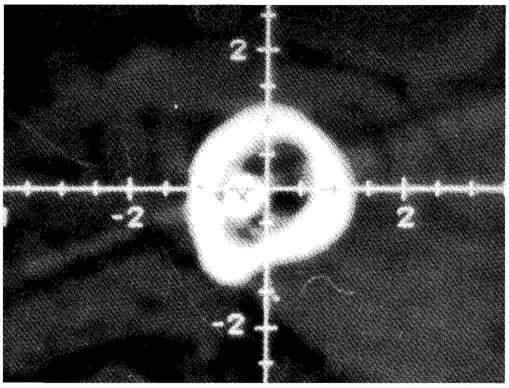


**Fig. 5.** CT scanning image of the stems at the level of the fourth zone. Based on the XY coordinate system, the stem tips are tilted to the posterior-lateral aspect (third quadrant) of the femoral medullary cavity; consequently, the position of the stem tip is defined as "d6 (−, −)".

## RESULTS

Results of this study appear below.

1. Center-to-center distance: 2.0 mm–9.8 mm, mean 4.75 mm (Table 1).

2. Radius of the femoral medullary cavity: 5.4 mm–11.8 mm, mean 7.96 mm.

3. Ratio of the center-to-center distance to the radius of the femoral medullary cavity: 0.23–0.83, mean 0.59.

4. Positions of the stem tip within the femoral medullary cavity are as follows:

Eight d4, three d6, two d7 and two d8 positions were observed in this group. 53% (8/15) and 20% (3/15) of these stems tilted to the anterior-lateral and the posterior-lateral aspects of the femoral medullary cavity, respectively.

5. Metal Artifact: At the fourth zoning-layer, clear images were obtained following adjustment of the CT window level. When the CT window width was 1500–2000 HU, a window level ranging from 500 HU to 600 HU was suitable for measurement and observation in this study. Under these conditions, the metal artifacts attributable to stem tips demonstrated minimal scatter that did not interfere with CT images; moreover, the borders of the femoral cortex and the stem were clear and sharp (Fig. 5).

## DISCUSSION

1. Advantages of this observational method include: 1) Intuition and convenience. The CT image, as a type of two-dimensional image, is superior to radiographs in terms of displaying the position of the stem of the hip prosthesis. Through cross-sectional CT scanning, the position of the stem tip in the femoral medullary cavity could be observed directly in great detail, including tilt degree and tilt direction of the stem tip. Antero-posterior radiography encounters difficulty with respect to illustration of the displacement of the stem in the antero-posterior direction, even when used in combination with lateral radiography. In other words, standard x-ray could not illustrate precisely the position of stem tips as it was unable to depict the position in two directions simultaneously, including antero-posterior and lateral-medial. Roentgen stereophotogrammetric analysis has been shown to possess high accuracy; however, this technique requires the attachment of markers to both the bone and prosthesis; 2) Quantification. With the aid of the coordinate system, the position of the stem tip in the femoral medullary cavity can be quantified by the related data. For instance, tilt direction of the stem tip can be established by the value of the quadrant, whereas tilt degree can be determined according to the center-to-center distance and the ratio of the center-to-center distance to the radius of the femoral medullary cavity. Recording and processing of these data by computer is convenient; moreover, the computer can analyze and contrast data; 3) High accuracy in measurement. Based on the CT rule, the center-to-center distance and the radius of the femoral medullary cavity can be measured automatically; the minimum value obtained in CT measurement was 1 millimeter. Most radiographs must be measured manually; furthermore, an error may occur in the measurement due to rotation of the stem or conse-

quent to the position of the tube [2].

2. Elimination of the metal artifact: Although CT images were affected by the metal artifact, it was possible to observe the position and orientation of a stem following surgery via CT scanning. Our results revealed that the intensity of the metal artifact could be altered by adjustment of the CT window level. The metal artifact could be reduced when the window level was increased, on the contrary this artifact became more serious. The metal artifact was minimal in the fourth zone of the hip prosthesis, and could be eliminated via adjustment of the window level. When the window level ranged from 500 HU to 600 HU, and the window width was 1500–2000 HU, clear CT images were obtained; in addition, the borders of the femoral cortex and the stem were clear and sharp. Under these conditions, an accurate number of measurements on CT images was possible.

3. Clinical significance of this method: 1) This technique is a novel observational method corresponding to the centralized status of the femoral component. The CT scanner provides the physician with a quantitative view of the position of the hip prosthesis including a display of the detailed position of the stem tip. Consequently, this regimen affords a more direct observational approach for clinical research. 2) Dynamic centralization. Researchers are concerned primarily with the correlation between centralization and aseptic loosening. A number of clinical studies have demonstrated[9,10] the existence of a strong correlation between these parameters. The prosthesis was not isolated and static, but dynamic and changing. The position of the stem established intraoperatively may be termed initial centralization; moreover, the postoperative position of the stem may be referred to as clinical centralization. A close relationship between the two centralizations is apparent. Initial centralization is extremely important, and can also affect clinical centralization. This observational method clearly visualized the position of the distal stem and permitted quantification. Comparison of the initial and the clinical centralizations and determination of the difference between them is highly desirable. In conjunction with the accumulation of quantitative data, future examination of the relationship between aseptic loosening, clinical symptoms, prosthesis longevity, and the quantified position of the stem is possible. Contrastive analysis of initial and clinical centralization may afford a basis via which to assess postoperative clinical outcome and the longevity of hip prostheses.

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