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Original Article

The Femoral Head Center Shifts in a Mediocaudal Direction During Aging

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ABSTRACT

Background: Accurate reconstruction of hip joint biomechanics is the key stone in total hip arthroplasty. Although proximal femur morphology is known to vary with both age and gender, few studies investigated this in the very elderly (ie, ≥80 years). The purpose of this study was to compare basic morphological parameters describing the position of the femoral head between very elderly and middle-aged subjects.
Methods: Computed tomographic scans of the femur of 90 very elderly (mean 84 years, range 80-105 years) and 58 middle-aged subjects (mean 52 years, range 20-79 years) were made. After 3-dimensional reconstruction, the neck-shaft angle, femoral neck anteversion angle, femoral head height, femoral neck length, and mediolateral offset (ML-offset) were determined.
Results: The neck-shaft angle was on average 3.6° less in elderly males (125.9° ± 5.0°) than in middle-aged males (129.5° ± 5.1°) ($P < .001$). The femoral neck anteversion angle was not significantly different between both age and gender groups. The femoral head height was −12.3 mm in elderly females compared to −10.5 mm (Δ 17%) in elderly males ($P = .284$) and even −8.0 mm (Δ 54%) in middle-aged males. The ML-offset was 10% (4.1 mm) larger in elderly compared to middle-aged males ($P < .001$).
Conclusion: These findings suggest that the femoral neck and head shift in a relative varus position during aging. Femoral prostheses with increased ML-offset and a lower caput-collum-diaphyseal angle are needed to accommodate the morphology of the femur in the very elderly. Care must be taken not to lengthen the operated leg, particularly in very elderly females.

The number of very elderly patients undergoing total hip arthroplasty (THA) for treatment of end-stage hip arthritis or a hip fracture is projected to increase during the coming decades [1-3]. Previous research has demonstrated that the morphology of the proximal femur varies significantly with both age and gender [4-7]. It is, therefore, likely that the anatomical position of the femoral head center (FHC) differs between the very elderly (ie, ≥80 years) and the average THA population (ie, 65-70 years).

Accurate reconstruction of hip joint biomechanics by THA is important in order to restore adequate abductor muscle strength [8,9] and range of motion (ROM) of the joint [8,10,11]. It also reduces the risk of postoperative complications such as gait disorders, hip dislocation, and wear of the prosthetic joint [10,12,13]. The biomechanics of the artificial hip joint can be adjusted by 3 parameters: the mediolateral offset (ML-offset) of the head center with respect to the mid plane of the body and the shaft of the femur, the anterior rotation of the prosthetic neck with respect to the coronal plane (the anteversion angle), and the vertical position of the head center with respect to the greater trochanter (GT) (ie, the leg length).

While the relative position of the pelvis with respect to the femur is a function of the morphology of both the proximal femur and the pelvis, adjustment of the acetabular rotation center during THA is limited and may lead to significant alteration in joint function. This has led to the development of femoral prostheses that replicate, as closely as possible some of the morphologic features of

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the proximal femur, both through the inherent design of the implant and its positioning within the femur. Thus, the ML-offset of the prosthetic hip is the lever arm for the hip abductor muscles and influences abductor efficiency [8-10], ROM [8], joint stability [14,15], cement and bone interface stresses [16,17], impingement [18], and wear [12,19,20]. The anteversion angle describes the ventral angulation of the hip stem and is thus related to the anterior offset of the head with reference to the coronal plane. The anteversion of the implant plays a major role in regaining a functional ROM and the prevention of dislocation [13,21-24]. Leg length is the final important parameter, and inadequate reconstruction of it has been associated with hip joint dislocation, gait disorders, and patient dissatisfaction [25]. The latter is the most common reason for litigation against orthopedic surgeons [26].

The primary aim of this study was to investigate whether basic morphological parameters describing the position of the femoral head (ie, neck-shaft angle [NSA], femoral neck anteversion angle [FNAA], femoral head height, and ML-offset) differ between very elderly subjects and middle-aged subjects. The secondary aim was to investigate whether gender differences exist regarding these parameters in the very elderly.

Materials and Methods

The very elderly group consisted of 90 healthy Caucasian subjects (40 females, 50 males) aged 80 years and older (mean age 84 years, range 80-105 years). A CT scan of their right femur was made as an extension of a medically prescribed scan. The main diagnoses for making the CT scan were inguinal pathology, benign prostate hypertrophy, and diverticulosis of the colon. Subjects with evidence of previous trauma, surgery, or bony pathology (metabolic disease or malignancy) were excluded. The CT scans were performed on a Siemens Sensation Open scanner (Siemens AG, Erlangen, Germany) with a scan field of view of 500 mm. The slice thickness was 1 mm, and every image consisted of 512 × 512 pixels, thus each having a size of 0.98 mm × 0.98 mm. The local institutional review board gave approval for this study, and all subjects gave written informed consent.

The control group consisted of 58 middle-aged cadaveric Caucasian subjects (4 females, 54 males) younger than 80 years of age (mean age 52 years, range 20-79 years). The femoral CT scans of these subjects were made post mortem using a General Electric Medical Systems LightSpeed CT scanner. The scan field of view was 384 mm, the slice thickness was 0.625 mm, and every image consisted of 512 × 512 pixels, thus each having a size of 0.75 mm × 0.75 mm. Causes of death mainly included road traffic accidents and drug overdoses. Subjects with evidence of previous trauma, surgery, or bony pathology (metabolic disease or malignancy) were excluded.

All CT scans were loaded into Materialise Mimics (version 10.01, Materialise, Leuven, Belgium). Cortical bone segmentation of the femur was done by selecting a threshold of at least 226 Hounsfield Units. The 3D model of the femur was loaded into the CAD software Rapidform 2006 (Inus Technology, Rock Hill, SC) for identification of bony landmarks and measurement of morphologic parameters.

Identification of Bony Landmarks

First, the mechanical axis of the femur was determined by defining the center of the femoral head proximally and the center of the knee distally (Fig. 1). The spherical parts of the subchondral surface of the femoral head were selected (at least 80% of the femoral head), and a sphere was fitted to these selected areas. The geometrical center of this sphere was defined as the FHC. At the distal end of the femur, the most prominent points on the medial and lateral epicondyles were identified. The vector connecting the medial epicondyle with the lateral epicondyle was defined as the transepicondylar axis. The midpoint of the transepicondylar axis was defined as the center of the knee.

An XYZ-coordinate system was created with the FHC as the origin as described by the Standardization and Terminology Committee of the International Society of Biomechanics [27] (Fig. 1). The line connecting the FHC with the center of the knee, also known as the mechanical axis, served as Y-axis (anatomically, the proximal-distal direction). The Z-axis was defined as a line perpendicular to the Y-axis (anatomically, the medial-lateral direction) lying in the plane passing through the FHC, lateral epicondyle, and medial epicondyle. The X-axis was defined as a line perpendicular to both the Y-axis and the Z-axis (anatomically, the ventral-dorsal direction).

A so-called table-top plane was created to simulate the orientation of the femur lying on a flat table with the most prominent points on the posterior condyles (medial: posterior point medial condyle, lateral: posterior point lateral condyle) and the GT_{post} contacting the supporting surface [28] (Fig. 2). The vector between the posterior point medial condyle and the posterior point lateral condyle was defined as the posterior condylar axis (PCA). The table-top plane was made by connecting the PCA and GT_{post}.

The proximal femur axis (PFA) was defined using a method based on the work of Maruyama et al [6]. The endosteal margin of the femoral cortex was delineated on a series of sections at intervals of 5 mm, extending from 25% and 35% of the total femur length, measured from the tip of the GT to the most distal point of the femur. Circles circumscribing each endosteal contour were constructed, and the line of best fit to the centers of the circles was defined as the longitudinal canal axis (PFA).

The reconstruction of the femoral neck axis (FNA) was based on the work of Sugano et al [29]. The isthmus of the femoral neck was defined as the region where the neck appeared to be narrowest. Within this region, one cross-section was constructed approximately perpendicular to the neck, and the external cortical boundary was circumscribed with a circle of best fit. The vector perpendicular to this circle was used as a first approximation of the true FNA. Along this vector, curves were fitted to the external cortical surface of the femoral neck at intervals of 1 mm. Circles were fitted to these curves to obtain centroids. A vector fitted to these centroids served as a second approximation of the true FNA. The NSA and the FNAA were measured in Rapidform (definition and technique described down below) and registered in Microsoft Excel. The process of fitting curves around a previous obtained vector was iterated until the standard deviation (SD) of all NSA and FNAA measurements was $\leq 1.5°$, excluding the first approximation. On average, 10 iterations were necessary to reach this level of consistency.

The tip of the GT_{tip} was defined as the most proximal point of the GT and was identified manually in 3 dimensions.

Definition of Morphologic Parameters

The dimensions and angles of the morphologic parameters were derived using standard mathematical routines embedded in the reverse engineering software (Rapidform) (Fig. 2). The NSA was defined as the angle between the FNA and the PFA projected on a coronal plane located onto the PFA and being parallel to the FNA. The FNAA was defined as the angle between the FNA and the table-top plane (ie, the PCA in the transverse plane). The ML-offset of the head center was defined as the length of the mediolateral component of a vector passing from the FHC to the PFA. The femoral neck length (FNL) was defined as the distance between the PFA and the FHC along the FNA, according the work of Michelotti et al [30].