Impact of Sex on Three-Dimensional Proximal Femur Morphological Parameters

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INTRODUCTION: Preoperative planning is important in hip resurfacing arthroplasty (HRA) for patient selection and determining the correct implant size and positioning. Proper patient selection, through quantitative methods, can aid in improving long-term patient outcomes [1]-[3]. Preoperative planning is multifaceted and includes joint morphology, mechanical loading, and material properties; these facets interact and impact each other and can be influenced by sex. Traditionally, morphological preoperative planning uses planar radiographs; however, the accuracy of planar measurements varies between 40.7 and 99.2% [3]-[10]. Moreover, morphological parameters relevant in the mechanical loading of the proximal femur may provide important insights for preoperative planning. The accuracy of morphological parameter measurements could be improved with three-dimensional (3D) methods. The objective of this study was to quantify the impact of sex on mechanically motivated 3D proximal femur morphological parameters in HRA patients.

METHODS: This retrospective study quantified 27 3D proximal femur morphological parameters in 219 (202 males and 17 females) HRA patients from preoperative computed tomography (CT) data from Kingston Health Sciences Centre's dataset. This study had Ethics Committee approval. Patient CT scans were segmented in Materialise Mimics; surface geometry was exported as stereolithography (STL) files. The 27 mechanically relevant morphological parameters were automatically quantified from the STL surface geometry using a custom MATLAB script. Morphology was quantified in a unique, patient specific, proximal femur coordinate system. The frontal plane was defined by the centre of the femoral head and the axis of the femoral shaft. The sagittal plane was defined by the axis of the femoral shaft and was perpendicular to the frontal plane. The transverse plane was perpendicular to both the frontal and sagittal planes. The origin of the femur coordinate system was the centre of the femoral head. The positive x-, y-, and z-axes pointed laterally, anteriorly, and proximally, respectively. The median and interquartile range (IQR) were reported for 27 morphological parameters, disaggregated by sex. All disaggregated morphological parameters were tested for normality using Shapiro-Wilk tests. Mann-Whitney U-tests were conducted to compare morphological parameter variation between sexes. All statistical analyses were conducted in OriginPro 2023b (Learning Edition) with a significance level of $p < 0.05$.

RESULTS SECTION: A total of 40 hips were excluded from the study because: the custom MATLAB script was unable to appropriately identify the femoral neck axis (27, 67.5%); unidentified errors in MATLAB (10, 25.0%), or the CT scan included < 5 mm of the femoral shaft so a femoral shaft axis could not be identified (3, 7.5%). The morphological parameters of 179 subjects (164 males and 15 females; 98 right and 81 left) were quantified by sex, reported as median (IQR). The male median (IQR) subject age, weight, and height were 52 (46-58) years, 96.7 (IQR 86.4-107) kg, and 180 (IQR 175-182) cm, respectively. The female median (IQR) subject age, weight, and height were 51 (IQR 46-59) years, 75.1 (IQR 70.1-88.9) kg, and 165 (IQR 163-171) cm, respectively. There were statistically significant differences between males and females for weight ($p < 0.001$), height ($p < 0.001$), femoral head radius ($p < 0.001$), horizontal offset ($p = 0.003$), shaft diameter ($p = 0.029$), anterior, posterior, and superior neck radii ($p = 0.001$, $p = 0.001$, $p = 0.007$), anterior-posterior and superior-inferior neck diameters ($p < 0.001$, $p = 0.004$), and the iliopsoas, gluteus medius, and quadratus femoris moment arms ($p = 0.005$, $p < 0.001$, $p < 0.001$).

DISCUSSION: Femoral head diameter and neck-shaft angle are commonly measured morphological parameters in HRA preoperative planning, while other parameters, such as neck diameter, horizontal offset, and head-neck junction concavity angles are often reported to assess different morphologies. The femoral neck length, 3D and frontal neck-shaft angles, head-neck offset, anterior-posterior and superior-inferior neck diameters, and horizontal offsets measured in the current study were similar to those reported in literature. Conversely, the femoral head radius, head-neck junction concavity angles, and head-neck ratios were larger than those reported in literature, while the neck-shaft angle in the transverse plane was smaller. A limitation of the current study was the uneven number of male and female patients. Only 8.4% of patients in the current study were females, reducing the statistical power. The current study investigated the effect of sex and side on proximal femur morphology through unifactorial statistical analyses, not multifactorial analyses. The scope of the current study only included proximal femur morphology. To wholly quantify hip morphology, the acetabular component must be assessed as well. The current study was also unable to measure the global offset, the horizontal distance between the body midline and the femoral shaft axis, which is relevant in joint loading. Lastly, the current study did not investigate the moment arms of every muscle that originates or inserts on the proximal femur, only five. The current study, however, found that sex impacts 40.7% of the measured proximal femur morphological parameters when assessing preoperative HRA CT scans with 3D quantification modalities.

SIGNIFICANCE/CLINICAL RELEVANCE: Quantified 3D hip morphology is an important component for preoperative planning; however, bone material properties and joint loads also play critical roles. The current study quantified the impact of sex on proximal femur 3D morphology which can be used to support patient selection. The current study, by developing a new semi-automated method for quantifying 3D proximal femur morphology, presented the critical first step for preoperative planning.

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