ISB 2013 BRAZIL
XXIV CONGRESS OF THE INTERNATIONAL SOCIETY OF BIOMECHANICS
XV BRAZILIAN CONGRESS OF BIOMECHANICS

PROXIMAL FEMORAL FRAME: APPLICATION IN CAM FEMOROACETABULAR SURGERY

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SUMMARY

The conventional reference frame for the femur has limited relevance for the planning of hip surgery as the femoral neck axis, a crucial reference for surgeons, has to be independently derived. The purpose of this study is to develop and validate a reliable frame of reference for the proximal femur.

Ten three-dimensional models of femurs were obtained. An iterative method was developed to find the femoral neck axis (X-axis). A second axis was also created from the lesser trochanter to the piriformis fossa (LTPF). The origin was defined as the femoral head centre. The cross product of the neck and LTPF axes provided the Z-axis and the cross product of the Z- and X-axes provided the Y-axis. Intra/inter-investigator reliability was assessed on the ten femur models; ten times by one investigator and twice by three investigators respectively. The results were then compared with the conventional reference frame to determine the repeatability and reliability of this novel method.

The femoral neck and LTPF axes had strong reproducibility, with mean intra/inter-investigator angle differences of 0.5° (±0.4°) and 0.7° (±0.5°), and 0.8° (±0.5°) and 0.9° (±0.6°) respectively. The variation of the X-, Y- and Z- axes were also considerably lower (±0.6°, ±0.7° and ±0.5° respectively) than the variations (±0.9°, ±2.5° and ±1°) in the conventional reference frame. A reliable method of obtaining the three-dimensional proximal femoral frame was developed, with greater relevance to preoperative planning and accurate assessment of procedures post-operatively.

INTRODUCTION

Reference frames are commonly used to describe limb kinematics and surgical operations. Before undertaking any procedure that may alter the relationship between the femoral head and neck and proximal femur, the surgeon needs to be able to describe them independently and reliably. Conventionally, the femoral reference frame uses both the proximal and distal femur and defining the references with respect to three anatomical landmarks; the centre of femoral head and the two femoral epicondyles [1]. A comparison of 12 different definitions suggested that replacing the epicondyles with the centroids of the epicondyles, condyle and anterior ridge of the trochlea groove constructed a reference frame that was the most reliable [1]. This method however, has several limitations when used for surgical procedures only on the proximal femur such as 1) unnecessary exposure to radiation, and 2) a relevance biased more towards kinematic measurements than clinical surgery. For example, the conventional frame of reference does not include the femoral neck axis, a feature commonly used to diagnose pathologies such as that of cam-type femoroacetabular impingement to determine the severity of the pathology [2] and for the planning of hip resurfacing surgery. The objectives of our study are therefore to 1) develop and validate a reliable frame of reference for the proximal femur, and 2) compare its reliability with the conventional reference frame [1].

METHODS

CT scans of ten, left-side hips were used in custom software and the femoral neck was obtained based on following: A first approximation of the neck axis was derived from two points: the centre of the femoral head and the centre of a triangle formed by three landmarks; the greater trochanter, lesser trochanter and the midpoint of the intertrochanteric line (Figure 1-A). A more reliable neck axis was then found via the following steps: (1) The preliminary neck axis was divided into 1mm cross-sectional slices perpendicular to the preliminary axis, outside the spherical extent of the femoral head. (2) The centre of gravity for each chosen slice was calculated (centroid) and a best fit line to these centroids was calculated (Figure 1-B). (3) A new axis was then measured as halfway between the preliminary axis and the best fit line. The process of calculating the centroids was repeated but this time using slices perpendicular to the new calculated axis. This process (stages one to three) was iterated until the axis converged to the point when the change between successive neck axes was less than 0.1°.

A second axis (LTPF axis) was obtained as a line between the centres of spheres fitted onto the lesser trochanter and piriformis fossa. The origin of reference frame was defined as the femoral head centre while the X-axis was the neck axis pointing medio-laterally. The cross product of the neck and LTPF axes provided the Z-axis, pointing antero-posteriorly and the cross product of the Z-axis and X-axis provided the Y-axis, in the superior-inferior direction. The conventional femoral frame suggested by Della Croce et al. [1] was defined as the base to which we compared the repeatability and reliability of method described here. To evaluate intra-investigator reliability, the neck and LTPF axes were obtained ten times on ten femurs by one investigator. For inter-investigator reliability, three investigators calculated the neck and LTPF axes twice each on five femurs. The data was assessed for normality using Kolmogorov-Smirnov test.

RESULTS AND DISCUSSION

A mean iteration of 15 (range 10 to 23) was required to achieve convergence of the femoral neck axis as defined by a successive angle change of <0.1°. The femoral neck axis was found to be highly repeatable with mean intra- and inter-investigator angle differences of 0.5° (±0.4°) and 0.7° (±0.5°) respectively. The LTPF axis also showed strong reproducibility with mean intra and inter-investigator angle differences of 0.8° (±0.5°) and 0.9° (±0.6°) respectively. The spread of spheres selected for the lesser trochanter and piriformis fossa was small, with a mean difference of 0.0mm (±0.1mm) and 0.0mm (±0.2mm) respectively for intra-investigator measurements. Low coefficient of variation values was found (<1°) suggesting that the data has low variance. The Kolmogorov-Smirnov test showed that the data was normally distributed. The variation of X-, Y- and Z- axes obtained from this study were on average considerably lower (±0.6°, ±0.7° and ±0.5° respectively) than the variations (±0.9°, ±2.5° and ±1°) reported by Della Croce et al. [1].

This small but detailed 3D study set out to develop a robust reference frame to describe the femoral neck and develop a proximal femoral frame of reference. To approximate the neck axis, the investigator had to choose slices (centroids) of the neck axis and a wide range (7 to 23) was chosen depending on the neck length. Identification of three initial anatomical landmarks (lesser trochanter, greater trochanter, midpoint of the intertrochanteric line) used to initially approximate the neck axis influenced how close the initial axis was to the actual axis and thus, the number of iterations required to achieve convergence. This contributed to the variation in the number of iterations (10 to 23) needed for convergence as it is difficult to reproduce the exact positions of the markers placed on each anatomical landmark every time. However by using the convergence rule (to achieve a successive angle change of <0.1°), it was possible to achieve almost identical axes regardless of the variation in the initial marking of the anatomical landmark.

This simple, and robust method of describing the femoral neck, independent of the femoral head has immediate advantages over the conventional reference frame. Precise preoperative planning of conservative arthroplasty can now be undertaken using a reliable method rather than a simple best guess, as the femoral neck axis is an essential reference for surgeons. Having a proximal frame of reference also permits reliable assessment of the surgery post-operatively to determine of how well a hip resurfacing or other conservative hip surgery has been carried out, with errors being reported in relation to the femoral neck axis in both angulation and translation. This reference frame may be used to define the femoral neck for planning and implantation using navigation or robot-assisted operations

CONCLUSIONS

In this study a reliable method of obtaining the 3D proximal femoral frame was developed. Having a proximal femoral reference frame confers several advantages over the conventional reference frame, including greater relevance to preoperative planning and permitting accurate assessment of the component post-operatively for surgeries such as hip resurfacing. Additionally, a novel accurate and reliable method of finding the 3D neck axis employed here, will allow precise quantification and diagnosis of femoral neck pathomorphologies such as cam deformities [2]. This reference frame has potential applications in defining the femoral structure for navigation and robotic systems in computer-assisted operations on the proximal femur [3].

ACKNOWLEDGEMENTS

We would like to thank the Wellcome trust and EPSRC for supporting part of this project.

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Figure 1: a) Rough estimate of neck axis using anatomical landmarks and b) accurate reliable neck axis using an iterative method.