Artificial Intelligence Aids Planning of the Femoral Stem in Hip Arthroplasty

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INTRODUCTION:

The morphology of the medullary canal of the proximal femur is seldom used for three-dimensional (3D) surgical planning of femoral stem version. Instead, the native femoral version (NFV) is used, but this has proven to be inaccurate as it is based on the external geometry of the femur.

In uncemented Total Hip Arthroplasty (THA), the stem locates itself by locking into the medullary canal. The final achieved position of the stem depends on both the shape of the medullary canal of the femur and the stem. Malpositioning of the stem can lead to impingement of the stem on the cup, accelerated wear of the bearing surfaces and a limited range of motion. 3D-CT studies show post-operative femoral stem version ranges from -30° retroversion to 60° anteversion.

The aim of this study was to better understand the shape variations of the medullary canal of the proximal femur to aid surgeons in the understanding of the version of an uncemented femoral stem. Our objective was to use computational modelling (statistical shape modelling (SSM)), to break down the complex shape of the medullary canal of the proximal femur into different simplified parts.

METHODS:

This was a retrospective cohort study. To build the SSM, a total of 64 preoperative pelvic CT scans of patients who subsequently underwent hip arthroplasty with an uncemented stem, were used.

We segmented the medullary femoral canal from the CT scans using an image processing and 3D rendering software. The shapes were aligned using a co-registration tool. An average femoral canal shape was then mathematically computed, which is an average representation of all 64 shapes used to build the model (Fig. 1).

To obtain a compact description of the shape variations between the femoral canals, the main shape variables (ways in which the shape of the femoral canals varied) in the dataset were identified using statistical modelling. The results were outputted in the form of modes of variations, ranked in order of decreasing contribution to the total variance in the dataset.

The outcome measures were:

1. The first 5 modes of variation of an SSM of the medullary canal shapes of the proximal femur;
2. The variance accounted by each shape variable (%).

RESULTS:

The first 5 modes of variation of the medullary canals were: 1. Size; 2. Rotation around the calcar; 3. Rotation around the long axis of the femur; 4.Varus/valgus tilt; 5. Femoral shaft torsion.

These 5 shape variables accounted for 84% of the cumulative variance.

The main distinguishing variable was size. This accounted for 36% of the total variance in the dataset (Fig. 2).

The other variables contributed to the variation in the shape of the medullary canal as follows: the second variable was summarised as an axial rotation which is fixed at the calcar situated in the inner side of the femur (accounted for 19% of the total variance), the third variable was a proximal torsion around the long/principal axis of the femur (accounted for 15% of the total variance), the fourth shape variable described changes in the varus/valgus orientation of the canal (accounted for 9% of the variance), and finally the fifth shape variable was identified as being femoral shaft torsion (accounting for 6% of the variance).

The shape variables 2, 3 and 5 identified in this study are all axial rotations that contribute towards understanding the achieved stem version, assuming that the prosthesis is sized correctly (Fig. 3).

DISCUSSION AND CONCLUSION:

The surgeon has limited intraoperative control over the position of a well-sized femoral stem in uncemented hip arthroplasty. The natural twist and bow of the canal guides the orientation of the implant. The large discrepancy reported between the planned and achieved femoral stem version is because the plan uses the shape of the external proximal femur and not the medullary canal. At present, no implant manufacturer can accurately predict the femoral stem version of their uncemented stems.

We are the first to mathematically characterise the shape of the medullary canal of the proximal femur. We are closer to being able to predict whether an uncemented stem will sit within the surgeon's target for femoral version prior to the surgery.

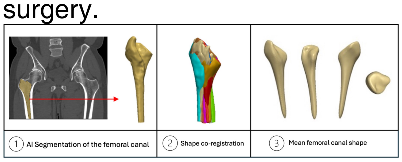

Figure 1. Summary of the framework for generating the mean femoral canal shape. Starting with segmenting the femoral canal from the CT data (1), to the alignment of the 64 shapes (2) and computation of the average anatomy (3).

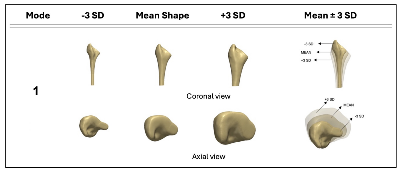

Figure 2. Visual representation of the first shape variable, attributed to variation in the femoral canal size. The two extremes of the canal size (smallest and largest) are presented as ± 3 standard deviations away from the mean shape.

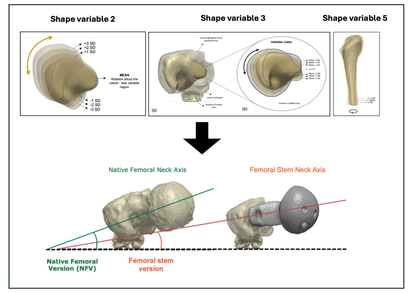

Figure 3. Visual representation of the shape variables 2, 3 and 5 (rotation around the calcar, rotation around the long axis of the femur and rotation of the diaphysis) showing how the mean femoral canal shape varies between ±3 standard deviations (SD). These three variables are all forms of axial rotations which contribute towards the achieved femoral stem version.