3D-CT Analysis of the proximal Femur Morphology in the Elderly as a Basis for Implant Fixation and Design.
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INTRODUCTION:
In cementless hip arthroplasty good fit and fill of the implant in the proximal femur is required to ensure high initial mechanical fixation against early migration and to limit micromotion to levels where bone ongrowth for long-term stability can develop. The endosteal morphology of the proximal femur as a basis for implant fixation and design has been described by Noble et al. in 2D using x-rays. He defined an endosteal canal flare index (CFI) and showed in the AP view that CFI decreased with age describing a transition from a "champagne flute" to a "stove pipe" femur. This reference data is limited to basic 2D information and as elderly subjects were defined as 60-90yrs of age, the number of very old individuals above 80yrs, a rapidly growing patient population for total hip replacement (THR), was too low to characterize morphological features of this critical patient group. The database also lacks information about patient characteristics beyond gender and age, such as height which may influence femoral dimensions.

In this study the endosteal and periosteal femur morphology of subjects ≥80yrs of age was studied in 3D using CT. Advantages are the standardised rotation of the femur, image quality, more accurate thresholding (Hounsfield units [HU] vs grey levels), the lack of x-ray overprojections, exact calibration and a quasi-continuous measurements. The research questions were 1.) to characterize the femur morphology of the very elderly patient in comparison to the younger population, 2.) to study the influence of subject characteristics such as gender or height on the morphological parameters and 3.) to investigate if the findings may affect the fit and fill of currently available implants.

METHODS:
CT images of high consistent quality (1mm slice thickness) were taken from 119 consenting elderly volunteers (m/f=65/54, avg. age: 84.1yrs [80-105y]) showing in their field of view the complete femur from acetabulum to condyles. Scans were processed using Mimics V12 software (Materialise, Belgium). The bone boundaries were identified by thresholding (226-1732HU). A vertical reference axis was drawn running through the canal's centre at the isthmus and 20mm below the lesser trochanter (LT). Femora were rotated into a standard position (linea aspera at medial). The femoral were resliced along the reference axis in 1mm planes. The endostea and peristea coordinates were analysed for width and wall thickness (total and in medial, lateral anterior, posterior direction), surfaces and flare indices at various levels and directions (Fig 1). While the method allowed these dimensions to be measured without overprojection, values from simulating this x-ray view were also calculated to make data comparable to literature findings.

Groups were compared using the Mann-Whitney, Wilcoxon or Student t-test when a normal distribution was confirmed.

RESULTS:
The ML dimensions (mean ±SD) for the simulated x-ray in AP view were at the isthmus 12.4 ±2.0mm and 44.3 ±5.8mm proximal to LT at level 0 resulting in a mean ML-CFI of 3.64. Dimensions including the x-ray overprojection were larger than values from the true axis by 0.5mm (+4%) at the isthmus, a mean of 7.9mm (29%) at LT and 4.1mm (10%) at level 0.

Based on dimensions from the true axis, the medial-lateral CFI was only 3.43 ±0.55, while the anterior-posterior CFI was smaller at 2.33 ±0.42 (p<0.001), a relative difference also found with x-ray projection. While the ML-CFI was the same for both genders, the AP-CFI was larger for men (2.43 ±0.44) than for women (2.21 ±0.36, p=0.004). The CFI based on endosteal surface area (7.20 ±2.15) was also larger for men (p=0.02, Fig. 2) and smaller than the product of ML (3.43) and AP (3.33) CFI. The gender difference in flaring was seen not only between isthmus and level 0 (standard CFI), but at all levels (Fig 2). Also when the baseline was moved up from the isthmus to the 80 or 60mm level, flaring remained larger in males. In both genders, flaring was not symmetrical with medial flaring (3.37) larger than lateral (2.96, p=0.001) and posterior flaring (2.62) larger than anterior 2.04, p<0.001).

Fig. 1: Measurement points & directions (top: true axis, bottom: x-ray).

Fig. 2: Surface CFI at any level with reference to isthmus.

The analysis of cortical wall thickness showed significant asymmetry between medial vs lateral and anterior vs posterior sides at most levels with the anterior wall being thinnest distal to LT (mean: 4.8-6.5mm) and the posterior wall being the thinnest proximal to LT (mean: 2.1-3.7mm). Walls were significantly thinner for women on all four sides and nearly all levels even when normalized to height (Fig 3).

Fig. 3: Lateral wall thickness (normalized to height) per gender.

DISCUSSION:
ML width at isthmus (12.4 vs 12.1mm) and zero level (44.3 vs 45.4mm) and ML-CFI (3.64 vs 4.05) were very close to literature values with a slightly wider isthmus and slightly smaller proximal width resulting in a lower CFI. This can be expected as subjects in this study were much older with a progressed transition to a stove pipe femur. Measurement error by x-ray overprojection was high especially at low CFI based on endosteal surface area (7.20 ±2.15) was also larger for men (p=0.02, Fig. 2) and smaller than the product of ML (3.43) and AP (3.33) CFI. The gender difference in flaring was seen not only between isthmus and level 0 (standard CFI), but at all levels (Fig 2). Also when the baseline was moved up from the isthmus to the 80 or 60mm level, flaring remained larger in males. In both genders, flaring was not symmetrical with medial flaring (3.37) larger than lateral (2.96, p=0.001) and posterior flaring (2.62) larger than anterior 2.04, p<0.001).

In the very elderly the transition to a stove pipe femur continues and results in a lower ratio between AP-CFI and ML-CFI, especially for men (3.47/2.43=1.4). Such reduced ML-flaring dominance, the gender differences in flaring and the asymmetry between anterior and posterior flaring should have influence on surgical templating, implant choice and even implant design in the very elderly. The common proportional scaling of the stem dimensions seems less appropriate than a matrix sizing scheme with ML and AP dimensions changing independently. Considering asymmetry and gender differences in wall thickness as well, the points of load bearing stem-bone contact must be selected with care.

REFERENCES: