

## Original Article

# Femoral stem sagittal balance - Do we need a new entry point?

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**Objectives:** Femoral stem positioning is of great importance in hip arthroplasty. Straight stem sagittal balance gains recently more attention in the literature. **Methods:** We performed a both clinical and cadaveric study in order to identify a possible ideal stem entry point at the level of the proximal femur, that ensures an optimal sagittal stem centering. We compared the sagittal tilt of 52 patients with femoral stem implantation in post-operative x-rays, dividing them in two groups depending on posterior neck cortex perforation. Subsequently, femoral neck osteotomy was performed in 40 cadaveric femurs. After placing an average straight stem, measurements of stem axis and femoral neck were made, in order to identify a possible area that could be used as a landmark, through which an optimal sagittal centering could be achieved. **Results:** Based on our results, stem sagittal tilt differed significantly when posterior neck was spared. In cadaveric evaluation, when posterior neck cortex was not perforated, the tip of stem was in contact with the posterior diaphysis cortex, thus malpositioned in the sagittal plane. We additionally found a statistically significant difference between neck centre and a) stem posterior boarder and b) neck posterior cortex distance. **Conclusions:** We conclude that placing the femoral stem just posteriorly to the posterior neck cortex, seems to be a good technique in order to achieve optimal sagittal balance of the femoral component.

**Keywords:** Femoral stem, Entry point, THA, Sagittal balance

## Introduction

Total hip replacement (THR) is one of the most common orthopaedic procedures. In the USA, the prevalence of THR was about 0,83% in 2010<sup>1</sup> corresponding to approximately 2,5 million patients. Complication rates tend to increase as primary THA procedures increase as well, resulting in a high clinical and economic burden<sup>2,3</sup>. Component malposition is a common factor for further complications, regarding joint stability and function<sup>4</sup>. Impingement and dislocation constitute a post-operative complication directly affected by improper component implantation<sup>5-7</sup> like stem anteversion discrepancy.

Femoral stem loosening has been also recognised as an additional complication even in modern stem designs. Data from studies by Hoenders et al<sup>8</sup> and Greenfield et al<sup>9</sup>, regard initial stem micro movement and early stage migration, as an independent negative predictive factor of implant loosening, acting as osteoclast differentiation stimuli. Camine et al<sup>10</sup> have also announced similar results about the negative effects of stem micro motion and migration, using a parametric model. Finally, femoral stem positioning is

regarded as a predisposing factor of periprosthetic fractures acting as a “stress riser”<sup>11,12</sup>.

Taking into account the importance of proper stem positioning, sagittal stem balance might play a critical role in these complications, especially on initial implant micro movement. While coronal stem centering has been traditionally controlled in order to avoid a varus or valgus positioning, sagittal centering is less studied in the literature, while its importance remains unknown. Husmann et al<sup>13</sup> examined four femoral canal flare indexes and described the difference between the anteroposterior (AP) and the mediolateral (ML) distances of the proximal femur, indicating

*The authors have no conflict of interest.*

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**Edited by:** Konstantinos Stathopoulos

**Accepted 28 February 2018**



**Figure 1.** Red line represents the femoral canal axis and black line the stem axis in both coronal and sagittal plane. The axes angulation in both planes (c-angle and s-angle) were calculated.

that an accurately templated stem in the AP view, does not premise a respectively accurate sagittal templating.

While several femoral neck osteotomies have been described depending on the surgical approach and stem design, in our clinical practice and when straight stems are used, we perform the classic osteotomy as described by Gibson and Moore<sup>14</sup>. Through this technique, we have made the observation that avoiding sparing the posterior cortex of the residual femoral neck after the osteotomy, the surgeon can obtain an optimal sagittal balance of the stem.

Our null hypothesis is that perforating the posterior neck cortex does not significantly alter the sagittal stem balance compared to the classic technique where the posterior cortex is spared.

In order to qualify our hypothesis, we performed a comparative clinical study followed by descriptive cadaveric evaluation.

## Materials and methods

### Clinical measurements

We retrospectively reviewed the medical files from 52 patients with hip arthroplasty, operated in our department from 2016 to 2017 using the same straight femoral stem. All patients had both anterior-posterior (AP) and profile post-operative x-rays. The operations were performed by two surgeons and the patients were divided into two groups, 24 in group A (operated by the first surgeon-posterior approach) where the posterior neck cortex was perforated and 28 in group B (operated by the second surgeon-posterior approach) where the posterior neck cortex was spared. Femoral neck osteotomy was identical in both



**Figure 2.** Scaling measurements using a metallic screw of predefined length.

groups, starting from the base of the great trochanter and proceeding perpendicular to neck longitudinal axis, ending at an average of 13,4 mm above the lesser trochanter. Post-operative x rays were evaluated measuring the deviation of stem axis to proximal femur axis in coronal (c angle) and sagittal (s angle) plane in both groups (Figure 1). In order to interpret and cross-check our preliminary clinical results, we made additional measurements on cadaveric femurs, using the same femoral neck osteotomy and the same type of stem as in surgeries.



**Figure 3.** Axes definition: - x axis is defined by the most posterior points of proximal and distal femur, - z axis is perpendicular to x axis.



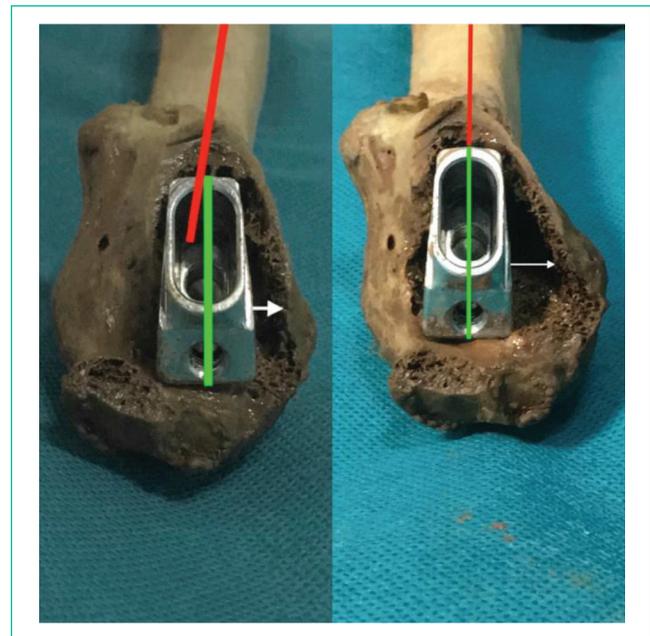
**Figure 4.** Definition of proximal bowing angle, as the angle between x axis (red dotted line) and an axis perpendicular to femoral diameter at the most distal end of lesser trochanter (black line).



**Figure 5.** Cadavers x-rays after initial reaming. On the left, the posterior neck cortex is perforated and the tip of the reamer is balanced. On the right, the posterior neck cortex is spared and the tip of the reamer is in contact with the posterior diaphysis cortex.

### Cadaveric measurements

We collected 40 cadaveric femurs from 18 men and 22 women. The median age was 66,4 years old (45 yo, 89 yo) while half of the specimens were right and half left. Neck osteotomy was performed perpendicular to the longitudinal neck axis, beginning from the greater trochanter root and ending at an average of 15,6 mm above the lesser trochanter. The femurs were then laid on a work bench of zero degrees of



**Figure 6.** Over the top macroscopic imaging of the femoral stem in the same specimen, using both techniques. Red line represents the proximal diaphysis axis and the black line the stem axis. White arrow shows the distance of the stem from the anterior neck cortex. **Left:** Posterior neck cortex is spared and the stem is anteriorly tilted. **Right:** Posterior neck cortex is perforated and the stem is properly aligned in the sagittal plane.

inclination, so that both the femoral condyles were in contact with the bench. They were thereafter photographed by a high resolution steady camera, using as focal point the middle of the femur from a distance of 50 cm, so that we gained a true profile view. All the measurements were performed working on "PixelStick" software program. A metal square of 15 mm was used as scaling balance (Figure 2).



**Figure 7.** Radiological imaging of the cadavers after stem implantation, using both techniques. **Left:** Posterior neck cortex is spared. The tip of the stem is impaired by the posterior diaphysis cortex. **Right:** Posterior neck cortex is perforated. The tip of the stem is properly balanced between anterior and posterior diaphysis cortex.

Two reference axes (x,z) were defined. The x axis included the most posterior parts of both condyles and the posterior part of the greater trochanter, on which the horizontally placed femurs balanced on the bench. The z axis is perpendicular to x axis (Figure 3). We defined the proximal bowing as the angle between the x axis and an axis perpendicular to proximal femur diameter at the most distal point of the lesser trochanter (Figure 4).

The next step was to proceed to stem implantation. Femoral canal was reamed using both techniques (posterior cortex sparing/penetration) and radiological images were obtained (Figure 5). Subsequently, the canal was enlarged with increasing diameter rasps using both techniques and both macroscopic and radiological images were obtained (Figures 6, 7). The relationship between the tip of stem and the posterior cortex was evaluated in all specimens.

Finally, after stem implantation and in order to define the ideal stem axis (p axis), two circles were drawn, as described by Boese et al<sup>15</sup>. The proximal circle with the centre on the z axis above the distal end of lesser trochanter and the distal circle with the centre on the midpoint of the femur, 150 mm distally to the first one, using a stem of 150 mm long and depth of 10 mm at the most proximal region. P axis was drawn between the two centres. The final axis (n) was drawn between the proximal and distal midline points of the neck (Figure 8).



**Figure 8.** Axes definition: - p axis (black line) is defined by the distal and middle circle centres. The distal circle is drawn at a distance of 150 mm representing the median stem body length, - n axis (red line) is defined by the centres of median and proximal circles.



**Figure 9.** Points explanation: - Point A: Neck centre, - Point B: p axis proximal end, - Point C: Posterior cortex on z axis, - Point D: Most posterior end of implant, - Translucent rectangle represents a femoral stem of 10 mm height. Distances definition: A-B: Centre to entry point distance (CED), A-C: Centre to cortex distance (CCD), A-D: Centre to stem distance (CSD).  $CSD = CED + 5mm$ .

We defined the angulation between p and n axes as anterior inclination of the neck. We thereafter measured 3 distances. The first, is the vertical distance (on z axis) between the centre of the neck and the p axis which we defined as centre-to-entry point distance (CED). The second, is the vertical distance between the neck centre and the posterior neck cortex and defined it as centre-to-cortex distance (CCD). Finally, we calculated the distance between the neck centre and the most posterior point of the stem and defined it as centre-to-stem distance (CSD), so that:  $CSD = CED + 5\text{ mm}$  (Figure 9). Max calcar thickness was also measured. The statistical analysis was made in order to identify if there is significant difference between CSD and CCD.

	Group A (24 patients)	Group B (28 patients)	Statistical significance
c-angle (deg)	0,11	0,4	p>0,05
s-angle (deg)	0,06	4,3	p<0,05

**Table 1.** Mean values of angle measurements in coronal and sagittal plane.

	Mean values	Max value	Min value
Anterior inclination (deg)	17,9	27,2	5
Proximal bowing (deg)	9,56	13,9	5,2
Calcar thickness (mm)	4,17	5,74	2,1
CED (mm)	9,62	13,64	8,94
CSD (mm)	14,61	21,9	9,67
CCD (mm)	11,31	13,64	8,94
CSD-CCD (mm)	<b>+3,3</b>	<b>12,26</b>	<b>-3,24</b>

**Table 2.** Measurements on cadaveric specimens.

## Statistical analysis

T-test for independent samples was used to compare the mean values of c-angle and s-angle deviations in clinical groups and the CSD and CCD in cadavers, after stem implantation. Pearson's correlation value was applied to identify the possible correlation between the stem entry point and anterior neck inclination angle and proximal bowing angle. The significance level was defined as  $P < 0,05$ .

## Results

### Clinical results

In both groups, coronal alignment of the femoral stem was optimal, with no significant difference. For group A, mean c-angle was 0,11 deg and for group B 0,4 deg ( $p > 0,05$ ). While coronal axes deviation did not differ, sagittal axes angle (s-angle) was significantly bigger in group B (4,3 deg) compared to group A (0,06 deg) (Table 1). All femoral stems in group A, were properly centered and the tip of stem was placed in-between the anterior and posterior cortex. In group B, all stems were anteriorly tilted (s-angle), while in 87%, the distal tip was in contact with the posterior cortex. No correlation was found between s-angle and c-angle in both groups ( $p > 0,05$ ).

### Cadaveric results

The mean anterior inclination angle was 17,9 deg ( $SD = 5,73$ ) and mean proximal bowing was 9,56 deg ( $SD = 2,4$ ). Mean distances values are shown in Table 2. All stems tip that were positioned with the posterior neck

sparing technique were in direct contact with the posterior diaphysis cortex. On the other hand, when posterior neck perforation technique was applied, stems tip was properly centered being in the middle between anterior and posterior diaphysis cortex. Independent samples t-test was applied to compare the mean values of CSD and CCD. CSD was found bigger than CCD in 32 of total 40 specimens (80%). There is a statistical significant difference between CSD and CCD ( $p < 0,004$ ). Interestingly, Pearson correlation test revealed no certain correlation between the anterior inclination angle and the CSD (Pearson correlation = 0,383,  $p = 0,106$ )

The mean difference between CSD and CCD was 3,3 mm. The unrelated values of anterior inclination and CSD reveal that placing the most posterior part of the femoral stem at a mean distance of 3,3 mm below the posterior cortex (in the profile view), gives a safe landmark for a proper sagittally balanced stem, independently of the variable native anterior inclination. In 80% of the specimens, the CSD ended in an area below the posterior neck cortex. The clinical interpretation of this finding is that the posterior neck cortex should not be spared while rasping, in order to achieve an optimal stem implantation.

Additionally, negative correlation was found between calcar thickness and CED (Pearson correlation = -0,484,  $p = 0,036$ ), but its' clinical importance cannot be evaluated.

## Discussion

Our study origins in the clinical observation that proper sagittal stem balancing is impaired by the posterior neck cortex. In order to validate our hypothesis, we retrospectively reviewed the radiological examinations of

52 patients with femoral stem implantation and created two groups accordingly to whether the posterior neck cortex was penetrated or not during rasping. Our results showed a statistically significant difference in anterior stem tilt (s-angle) when posterior neck was spared (group B). Even though the same surgical approach was used in both groups, we regarded different surgeons as an independent factor that could alter our results.

Trying to eliminate all imponderables and further understand the role of proximal femur anatomy role in stem sagittal balance, we further performed a cadaveric study simulating the proper neck osteotomy as it is performed intra-operatively. The radiological evaluation after simulating the stem implantation showed that when posterior neck cortex was spared, the tip of femoral stem was in contact with the posterior diaphysis cortex, thus the stem was not properly balanced in the sagittal plane. Since the proximal neck was involved, we reversely attempted to identify guiding anatomical landmarks in order to achieve optimal sagittal implantation of the femoral stem.

Native proximal femur anatomy is complex. The definitions of anteversion and antetorsion are commonly misleading, since they do not clearly describe the same variable in the literature, while the proper measurement is susceptible to significant intra-observer disagreement even using advanced computed tomography (CT) protocols<sup>16</sup>. We agree with Müller et al<sup>17</sup>, about their definition of functional anteversion as a sum of rotatory and tilted anteversion. In accordance to our results, a false entry point results to deviations of the final stem anteversion, a situation that has been proved to lead to increased rates of impingement and/or dislocation<sup>5,15</sup>.

In our cadaveric study, all the p axes ended at an area, at a level lower than the centre of the neck on sagittal plane. Even though the observed anterior inclination of the proximal femur is the obvious explanation of this phenomenon, the clinical importance is critical as far as the sagittal stem balance is concerned. In addition to the importance of proper sagittal centering on the functional anteversion, there are also concerns about the role on stem size. A tilted rasping is more possible to be disrupted by the anterior or posterior cortex leading to an undersized stem selection and thus to decreased stem stability<sup>18</sup>. Noteworthy, since initial stem micro movement has been long recognized as a key-factor of loosening, sagittal centering might gain more attention.

We found a statistically significant difference between CSD and CCD with CSD being bigger. The clinical importance of this difference, is that the posterior neck cortex should not be spared while rasping the proximal femur, otherwise a tilted implantation is more possible.

In our cadaveric study, we had a relatively big range of stem maneuver at the level of the entry point. In clinical practice though, the surrounding soft tissues as well as the relevant range of motion of the dislocated femur, can be an obstruction. Vaughan et al<sup>19</sup> calculated that through

the anterolateral approach, the final anteversion was significantly higher compared to the posterior approach, indicating that the difficulty of posterior neck cortex rasping is important. Additionally, one more study by Abe et al<sup>20</sup> had similar results, referring a significant sagittal alignment change, when direct anterior approach was performed.

In conclusion, taking into account our data in accordance to the results above<sup>19,20</sup> rasping the proximal posterior neck cortex (as well as the intra-operative ability to do so), seems to provide a good landmark that lead to proper sagittal stem implantation.

There are several limitations of this study. First of all, we examined our hypothesis in accordance to straight femoral stems. Anatomic stems as well as short stems might not be influenced by the sagittal centering and in turn, they do not seem to interfere with the proximal femur stress shielding and thus, loosening<sup>21</sup>. Even though we examined the correlation of stem sagittal tilt and final functional ante-version and their impact on prosthetic joint function, we have not taken into account the corrections that can be applied through changing the cup version<sup>22</sup>. Worlicek et al<sup>23</sup> found a final ante-version change of about 21,5 degrees which even if it is significant, may not interfere to the prosthetic joint kinematics if the combined (stem and cup) ante-version is between normal ranges. Additionally, all the measurements were applied on normal femurs excluding deviational anatomy that is not uncommon in clinical practice. Finally, more long-term studies are needed in order to identify the true clinical impact of sagittally tilted stems in the viability of THR.

#### Acknowledgements

*The authors would like to thank and mention Prof. J.Vlamiš for the study planning and guidance.*

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