Influence of the femoral head screw position on the risk of cut-out in trochanteric fractures: a computational analysis

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Abstract: Cut-out of the hip screw is the most common mechanical complication for all implants used to treat trochanteric fractures and occurs when the screw perforates the femoral head surface. One of the factors that influence the incidence of this complication is the position of the screw, which can be characterized by the tip-apex (TAD) and calcar tip-apex (CalTAD) distances. Although frequently discussed in the literature, there is no consensus on the best implant position to reduce the risk of cut out. The applicability of TAD and CalTAD as parameters that predict the risk of this complication has also been questioned. Thus, the goal of this study is to analyse the biomechanical behaviour of different positions of the screw within the femoral head along the medial-lateral and inferior-superior directions. To accomplish this, a Proximal Femoral Nail Anti-rotation implant was modelled and finite element models of a right femur were developed using CT images. Two loading cases (walking and stair climbing) were simulated and a real density distribution was attributed to the femur. The minimum principal strains in the bone were used to investigate and compare the biomechanical performance of eight models with different screw positions in the inferior and central regions of the femoral head with 5, 10, 15 and 20 mm from its surface. Overall, the position less likely to lead to cut out was in the inferior region with a 10 mm distance. In a central position, the movement of the screw along the medial-lateral direction is not relevant. The results attributed a stronger predictive value to CalTAD.

Key words: Femur, Trochanteric Fractures, PFNA, Screw, Finite element model.

1. Introduction

Proximal femoral fractures are among the most sustained fractures and they typically occur in older people. With the aging of the population, the frequency of this injury is increasing, especially of the trochanteric type [1,2]. The consequences of trochanteric fractures in the elderly population are significant in terms of lives lost and are associated with early and late complications, such as thromboembolism, infections and mobility problems [3–5]. Besides, as this group of people is characterized by a decreased physical capacity, concomitant systematic diseases, and increased vulnerability to environmental dangers, even low-energy trauma can cause femoral trochanteric fractures. The aim of the treatment of proximal femoral fractures is to help patients to recover to the closest degree of activity they had before the trauma. The most appropriate treatment must be considered for the patient to be able to move immediately after the surgery, allowing full weight bearing, which contributes to fracture healing, and preventing possible complications that may result from a prolonged bed rest [1,6]. The best implant available used to treat trochanteric fractures is the Proximal Femoral Nail Anti-rotation (PFNA), which uses a blade rather than a screw, increasing the contact area between the bone and the implant and providing angular and rotational stability [7].

Cut-out of the femoral head screw is one of the most frequent mechanical failure modes, with a reported incidence ranging from 2% to 8%. This complication occurs when the neck-shaft angle decreases, forcing the screw inserted into the femoral head to migrate and perforate the hip joint surface [8–10]. This complication is affected by patients' age and sex, bone quality, fracture pattern, quality of reduction, implant design, screw positioning in the femoral head and the neck-shaft angle. To decrease the risk of cut-out, it is important to ensure a good fracture reduction and the right positioning of the implant in the bone, as these factors are the ones that can be controlled by the surgeon [4,11,12]. Numerically, the position of the screw can be characterized by the tip-apex distance (TAD) and the calcar tip-apex distance (CalTAD), which are techniques that indicate the distance between the tip of the screw and the femoral head surface. Although it is believed that these distances have a correlation with the risk of cut-out, their applicability as predictors of this complication have been recently questioned [13,14].

Many studies in the literature have focused on the biomechanical effect of the position of the screw in the femoral head. Computational studies used finite element models with the screw placed in different regions along the inferior-superior and anterior-posterior directions of the femoral head to find a position that causes less damage to the bone [3,8,9,15]. It is unanimous that the anterior, posterior, and superior regions are the worst positions to place the screw. However, there is no clear consensus regarding the remaining regions, since the studies' findings are divided between the inferior and central regions of the femoral head as the best positions to insert the screw, which complicates the decision of the surgeon [8,11,16]. Regarding the medial-lateral direction, the technique guides of the implants recommend placing the screw with a distance of 10mm from the femoral head surface to avoid cut-out [17]. However, to the author's knowledge, no studies have investigated the impact of moving the screw closer or further away from the surface of the bone.

The present study is motivated by the existence of contradictory findings in the literature regarding the best position to place the femoral head screw in the inferior-superior direction and by the lack of knowledge regarding the impact of moving the screw along the medial-lateral direction on cut-out. Considering three-dimensional finite element (FE) models of different implant positions along these two directions, the aim of this study was to investigate the best position for the blade to reduce the risk of cut-out using the PFNA. The secondary goal of this work was to evaluate the applicability of TAD and CalTAD as predictors of cut-out.

2. Methods

A three-dimensional (3D) model of the right femur was obtained by the segmentation of Computed Tomography (CT) images from a 38-year-old male acquired by the Visible Human Project [18]. The software used to perform the segmentation process of the bone was ITK-SNAP (version 3.8.0, 2019). The 3D solid model of the right femur was then used to develop its FE model in Abaqus (version 6.14-1, 2014). An unstable fracture defined as 31-A2 in the Müller AO classification was simulated according to Goffin et. al [9]: a 43º angle between the fracture line and the femoral shaft was defined and the intrusion distance of the medial fragment into the fracture complex was assumed to be 30%. The fracture divided the femur into three fragments: the superior part (SP), which includes the femoral head and neck and the superior part of the greater and lesser trochanters, the inferior part (IP), containing the femoral shaft and the inferior part of the greater and lesser trochanters and the missing fragment corresponding to lesser trochanter.

The bone was modelled as a linear elastic and isotropic material. The real density distribution of the femur was estimated from the CT images using an Abaqus plug-in called bonemapy. The Young's moduli (E) were computed from the density values through the following density-elasticity relationship [19,20]:

$$E = 6850{\rho_{app}}^{1.49} \qquad (1)$$

where ρ_{app} is bone apparent density in g cm^{-3}. The resulting density and Young's modulus ranges for the entire bone were $[0.01 - 1.86]\ \mathrm{g\ cm^{-3}}$ and $[7.17 \times 10^{-3} - 17.3]\ \mathrm{GPa}$, respectively. To correct the partial-volume effect, the maximum density was attributed to the superficial nodes of the femur. In addition, two shells were created for the SP and IP of the bone with a 0.5 mm thickness and a Young's modulus of 17.3 GPa to simulate the outer cortical shell. The Poisson ratio (ν) was defined as 0.3 for both the bone and shells.

The implant used in this work was the PFNA and its components were modelled using Solidworks (Education Edition, Academic Year 2017-2018). According to the PFNA technique guide [17], the implant is composed of a nail, inserted along the femoral shaft, a blade, placed in the femoral head, and a locking screw, used to lock the distal end of the nail, as shown in Figure 1.

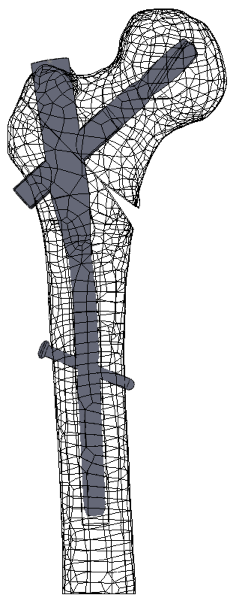

Figure 1 - Anterior view of the 3D model.

Overall, 8 configurations were considered by varying the blade position along the medial-lateral and inferior-superior directions. The blade was aligned with the centre of the femoral head, for the central geometries, and was placed 13.5 mm below that point, for the inferior geometries. For each of these regions, medial-lateral positions distancing 5 mm, 10mm, 15 mm, and 20 mm from the femoral head surface were defined. The implant is made of a titanium alloy (Ti-6Al-7Nb), characterized by $\mathrm{E} = 105\ \mathrm{GPa}$ and $\nu = 0.3$ [21]. Its material was modelled as linear elastic, homogeneous and isotropic.

For the bone-shell interactions, tie constraints were defined considering the bone as master and the shell as slave. A similar condition was also considered for the interaction between the locking screw and bone since this region was expected to have little impact on the femoral head. All other interactions were defined as surface-to-surface contact with different friction coefficients taken from the literature: 0.46 for bone-bone, 0.2 for implant-implant [8,9], and 0.3 for bone-implant [22].

In this work, two load cases were simulated according to Bergmann and Heller [23], which includes the hip contact load and a set of simplified muscle forces. For the normal walking case the muscles correspond to the abductor, tensor fascia latae (TFL) and vastus lateralis (Figure 2-A), whereas the stair climbing case also includes the action of the ilio-tibia tract (ITT) and vastus medialis (Figure 2-B). The distal end of the femur was fully fixed with an encastre condition to restrict all displacements and rotations and prevent rigid body motion.

Due to the complexity of the structures being modelled, quadratic tetrahedral (C3D10) elements were used to define the finite element meshes of the bone and the implant. The shells were defined with quadratic triangles (STRI65). To assess the accuracy of the model, the minimum principal strains observed in three points of the femoral neck were evaluated. The optimal mesh was found to have an average element size of 2 mm for the SP of the bone, its shell and the blade and 3 mm for the IP, its shell, the nail and the locking screw.

The verification of the bone properties was performed by comparing the average density of the femoral neck, the neck-shaft angle and the femoral head diameter obtained in this study with the literature. To evaluate the risk of cut-out, qualitative and quantitative comparisons were performed between the different finite element models. Based on the assumption that cut-out incidence is more likely to occur due to high compressive strains in the femoral head and neck [9], the minimum principal strains in these regions were evaluated qualitatively through visual inspection of their distribution. In addition, the bone volume susceptible to yielding in

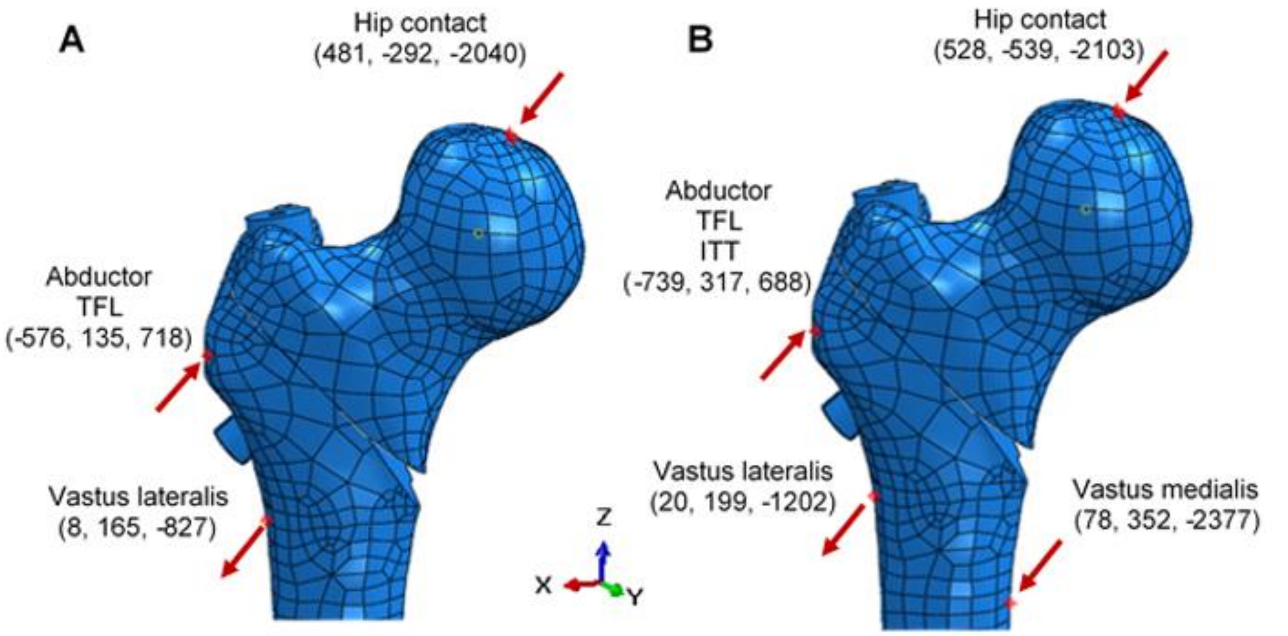

Figure 2 – Identification of the application points and the loads' magnitude: (A) normal walking case (B) stair climbing case.

the SP and proximal part of the IP (SP-IP Region) were computed and compared among the eight geometries. The yielding volume at the tip of the blade (Tip Region) and at the transition region between the head and tail of the blade (HT Region) were also calculated, since according to Goffin et. al [9] the region around the blade might be critical for cut-out. Yielding was assumed to have occurred for a given bone point whenever the minimum principal strain exceeded the compressive yield strain value of the human bone (-0.84%) [24]. A greater volume was expected to represent a higher risk of cut-out. The distances of TAD and CalTAD were measured and a relationship with the risk of cut-out was attributed through the calculation of Pearson correlation coefficient.

3. Results

The average density of the femoral neck obtained in this study was 383.8 mg cm^{-3} and the values measured for the neck-shaft angle and femoral head diameter were 128º and 54.58 mm, respectively.

Figure 3 presents the minimum principal strain distribution of the walking case in a coronal section of the head and neck of the femur for all geometries. Since the results for the stair climbing case are similar to those of the walking case, only the results for the latter are shown for the sake of brevity. Common to all geometries, low strains, more compressive, are observed in the superior region of the femoral head, closer to the surface. In addition, the contact region between the superior and inferior parts of the bone presents the largest volume with the lowest strains, below the yield strain of -0.84%. Comparing the FE models with the blade placed in the inferior and central regions, the yielded bone volume, illustrated by black regions, is larger in the contact region for the central geometries. For the inferior models, black regions are also identified at the tip of the blade and around the transition between its head and tail, especially above the blade. Comparing the positions along the medial-lateral direction, there are no significant visual differences, except for the head-tail transition in the inferior

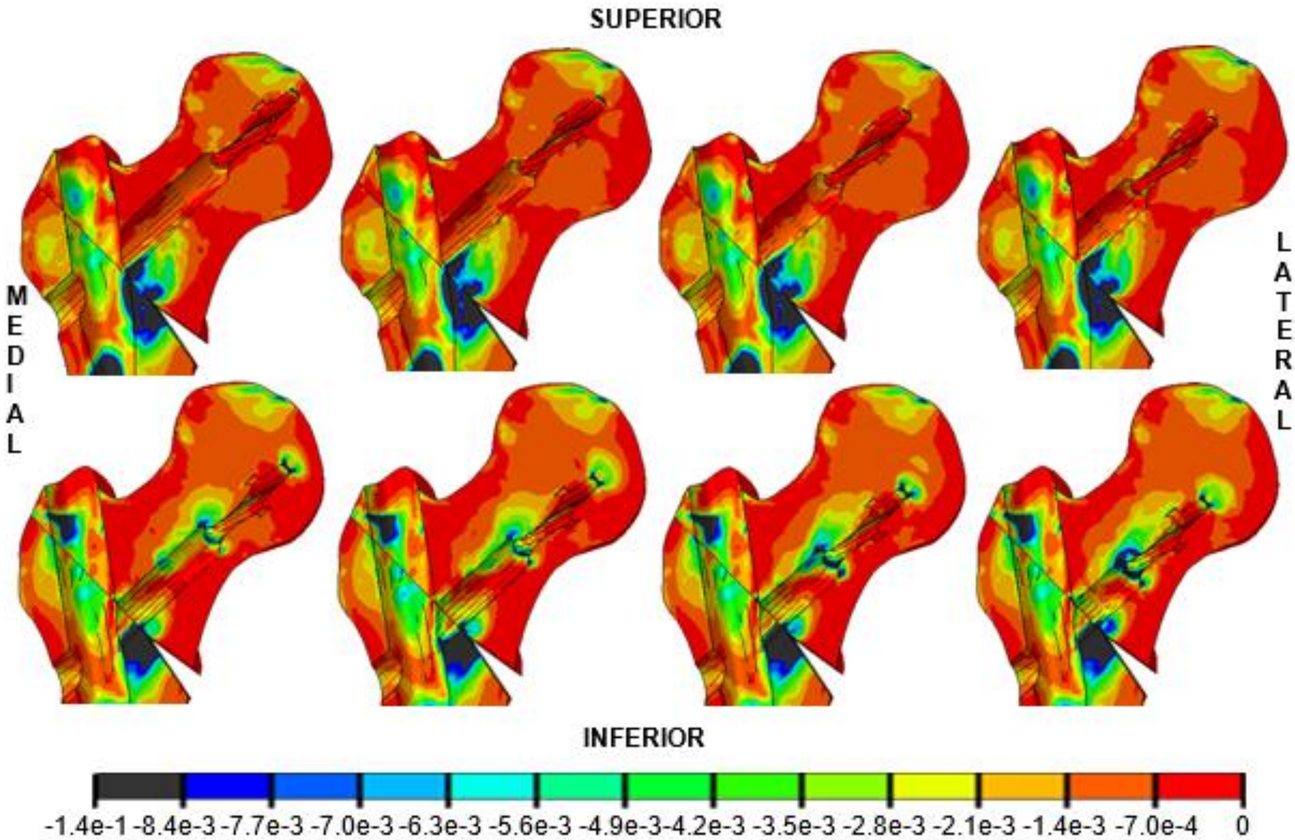

Figure 3 - Minimum principal strains in a coronal section of the proximal region of the femur for the stair climbing case. The minimum of the strain scale is defined as the yield strain of the human bone (-0.84%) to emphasize the regions of the bone more susceptible to undergo irreversible deformations (black areas).

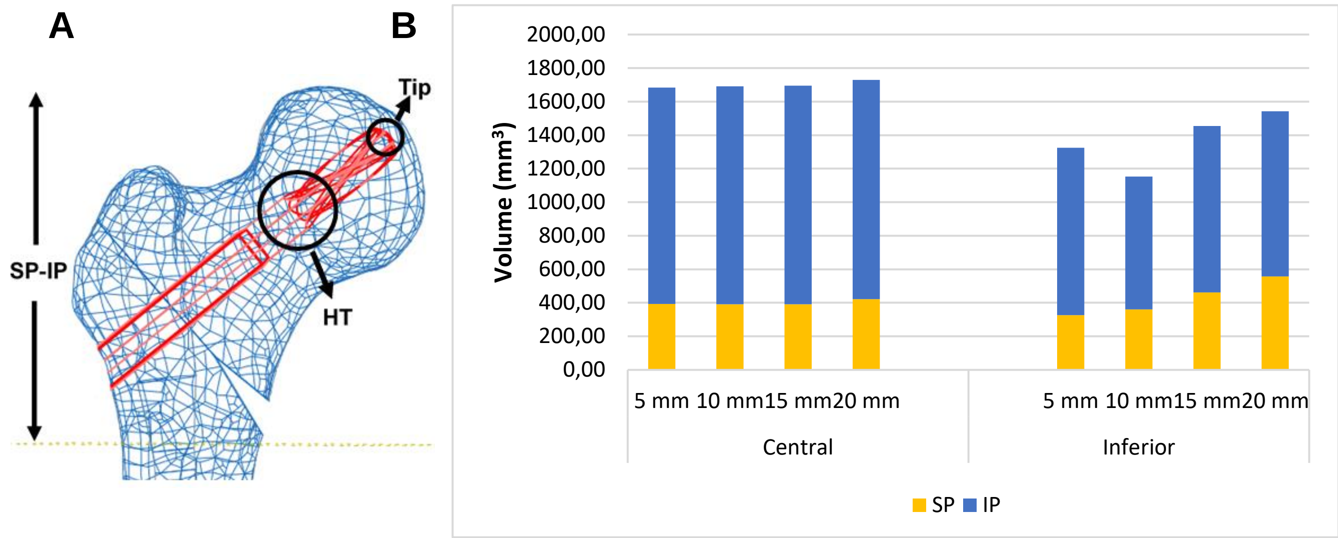

Figure 4 – (A) Representation of the SP-IP Region (bone above the dashed green line), Tip Region (bone inside the sphere at the tip of the blade) and HT Region (bone inside the sphere around the head-tail transition). (B) Volume of bone in the SP-IP Region with minimum principal strains below the compressive yield strain of 0.84%. The contributions of the superior (SP) and inferior (IP) parts are also detailed.

geometries, in which the black area increases from 5 to 20 mm.

Figure 4-B presents the volume of the SP-IP Region (Figure 4-A) with compressive strains smaller than -0.84%, with the contribution of both the SP and IP specified. Overall, the contribution of the IP of the bone is more relevant than that of the SP. The volume obtained for the geometries with the blade placed in the central region of the femoral head is very similar for all medial-lateral distances considered, even though a small increase is observed for the 20 mm distance. These FE models present a higher volume of bone susceptible to yielding than the geometries with the blade in the inferior regions. Focusing on the inferior geometries, the volume of the SP increases as the blade is moved away from the femoral head surface. However, in the IP, the volume appears to be similar for all but the 10 mm distance in which it is evidently smaller, representing the model with the lowest volume of damaged bone. Regarding the Tip and HT Regions (Figure 4-A), it only represents about 14% of the entire volume of SP-IP Region, which means that the damaged bone is mainly restricted to the contact region between the fragments.

The distances of TAD and CalTAD of the eight geometries were measured (Figure 5) to evaluate their relationship with the cut-out incidence. As expected, both distances increase as the blade is placed further away from the femoral head surface. Comparing the two techniques, for the central geometries, CalTAD is larger than TAD, whereas for the inferior geometries, it is smaller. In addition, the difference between the distance measured for 20 mm and 5 mm is smaller for CalTAD, which means that a movement of the blade along the medial-lateral direction leads to higher differences in TAD than in CalTAD.

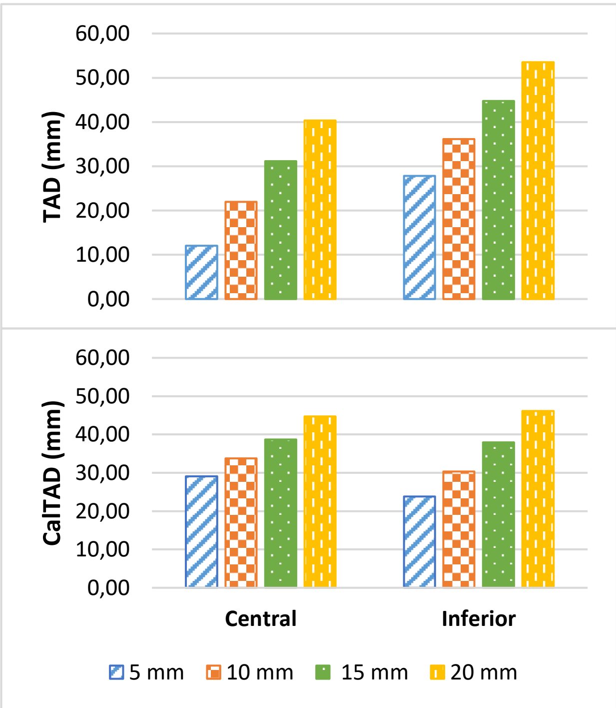

Figure 5 - TAD and CalTAD values for the eight positions of the tip of the blade within the femoral head.

Pearson correlation coefficient were computed between these two distances and the volumes susceptible to yielding of Region 1. Three correlation coefficients were computed for each measurement technique: one for the eight FE models together, an additional one considering only the four geometries with the blade inserted in the central position and another only for the inferior geometries (Table 1).

Table 1 - Pearson correlation coefficient between TAD and CalTAD, and the volume with strains smaller than -0.84% for the SP-IP Region.

Models	TAD	CalTAD
All	-0.24	0.48
Central	0.88	0.92
Inferior	0.73	0.75

Regarding TAD, a very weak negative correlation was found for the eight geometries, which would indicate that higher values of TAD correspond to smaller risks of cut out. On the other hand, CalTAD has a moderate positive correlation with the risk of cut-out, meaning that increasing this distance leads to a greater risk of this complication. By looking only to the central and inferior regions in separate, the correlation between both distances and the volume susceptible to yield is positive and stronger, especially in the central region. Comparing the two techniques, CalTAD presents stronger correlation coefficients than TAD for all cases.

4. Discussion

The computational studies in the literature that focused on the position of the femoral head screw did not assess all possibilities as their evaluation was mainly restricted to only two directions: inferior-superior and anterior-posterior. It is consensual that the most appropriate position for the insertion of the screw on the lateral view is the central position, but on the anteroposterior view, the conclusions differ between the central and inferior positions Considering the most suitable implant to treat unstable trochanteric fractures (PFNA), this work aimed to contribute to the existing knowledge on the best screw/blade position by evaluating its position along not only the inferior-superior direction but also the medial-lateral direction. To the author's knowledge, this is the first exhaustive computational study about the impact of moving the blade/screw along the medial-lateral direction. For the sake of simplicity and considering that most implants use a screw instead of a blade, from now on the blade will be referred as screw to allow a general evaluation of the results obtained in this study

The average density obtained in this study is within the limits of the literature range (317 – 415 mg cm^{-3} [25]), which is a good indicator that an adequate density distribution was attributed to the FE model of the bone and that it is similar to the real characteristics of the femur of young males. In addition, the femoral head diameter and the neck-shaft angle also fall within the range found in the literature for young males (113.2 – 148.2º [26]; 40.20 – 59.00 mm [27]). All these findings provide confidence in the finite element model developed, which is expected to be representative of femurs in general, and, consequently, in the results.

The minimum principal strains distribution along the superior and inferior fragments of the bone is coherent with previously published studies [8,9]. Overall, higher compressive strains were observed in the superior region of the femoral head, closer to the surface, which is a result of the hip contact load applied in that region. Since the z component of the force is negative, it compresses the femoral head, resulting in high compressive strains. The contact region between the fragments is the largest with damaged bone, being this the primary location that contributes to the incidence of cut out. This occurs probably due to the moment created in that region by the force applied on the femoral head and the absence of the medial fragment causes lack of medial support, contributing to the moment and increasing the compressive forces, which results in low minimum principal strains. Regarding the computed yielding volumes, the obtained values are smaller than the ones reported by Goffin et. al [9], as already expected since that study used an extramedullary implant which increases the instability of the device causing higher compressive strains. On the other hand, the values are similar to those of Pei-Yuan Lee [8] who also used an intramedullary implant.

Positioning the screw in the inferior region of the femoral head reduces the damaged bone in the contact region between the superior and inferior fragments. This can be explained by a lower position of the screw, restricting the femoral head rotation and reducing the pressure caused in the contact region of the bone. In addition, when the screw is placed on the central region, only one support point is provided, which is the contact point between the nail and the screw, since the surrounding bone is characterized by low density values. In a position closer to the inferior region of the femoral head, an additional support is provided by the femoral calcar, which is a dense region. In the inferior region, the screw is very close to the missing medial fragment, thus the load is transferred to the screw, increasing the stress in this component and, consequently, relieving the bone in the contact region. However, due to this phenomenon, the screw exerts greater forces on the bone around it, which is expressed by high compressive strains along the screw. This explains the black areas and the yielding volume obtained around the tip of the screw and in the head-tail transition. Therefore, when the screw is inserted in the inferior position, the stability of the implant increases, reducing the pressure caused in the contact region of the bone, but increasing the forces acting on the bone around the screw. Consequently, along the inferior-superior direction, the best place for the insertion of the screw seems to be the inferior region of the femoral head, which is in line with the findings of Cheng Hung Lee et al. [3], Pei-Yuan Lee et al. [8] and Goffin et. al [9]. However, Konya and Verim [15] suggested a central positioning for the screw, which may be due to the application of a different evaluation method, based on the von Mises stresses in the implant.

Considering only the central geometries, no significant differences were observed in the computed volume when the screw was moved from 5 to 20 mm. This suggests that the medial-lateral positioning of the screw has little impact on the risk of cut-out when the screw is in the central region. Therefore, orthopaedic surgeons have a margin for error without compromising the patient’s health. The recommendation of the PFNA surgical guide to place the screw at 10 mm from the femoral head surface is thus appropriate, even though a central rather than an inferior position is suggested. Regarding the models with the screw in the inferior position, at a 10 mm distance from the femoral head surface, the volume of bone susceptible to yield is smaller which means that the risk of cut-out is lower. Thus, the most stable position to place the screw is in the inferior region of the femoral head, 10 mm away from the surface. As mentioned, to the author’s knowledge no studies have assessed the impact of moving the screw in the medial lateral direction. Hence, no direct comparisons with the literature are possible.

To understand the applicability of TAD and CalTAD, the Pearson correlation coefficient was computed for the eight geometries together and for the inferior and central models in separate, considering the SP-IP Region. Overall, CalTAD presented a stronger correlation with the risk of cut-out than TAD, contrary to what has been reported in the literature [13,14]. This may result from the different positions chosen for the screw, including inferior-superior and anterior-posterior rather than central-inferior and medial-lateral positions as performed in this study. Most of the obtained coefficients were positive, meaning that higher values of TAD and CalTAD represent a higher risk of cut-out, which is in agreement with the findings of most of the clinical studies found in the literature [4,10,12,16,28,29]. However, none of the computational studies [3,8,9,15] reached this conclusion, reporting either a negative or a null correlation. Again, this may be explained by the different chosen position or it may be due to the simultaneous evaluation of all positions instead of a separate evaluation by central-inferior position as performed in the present work.

Considering only the central geometries, a very strong correlation was found for both TAD and CalTAD, which was expected since the computed volume was observed to increase as the screw moved further away from the femoral head surface. Being the difference between 5 and 20 mm smaller for CalTAD, a higher coefficient was expected for this technique because the differences obtained for the calculated volume were also small. These results suggest TAD and CalTAD to be good predictors of cut-out when the screw is positioned in the central region of the femoral head. Regarding the inferior FE models, the correlation coefficients for both TAD and CalTAD were smaller due to the non-linear evolution of computed volume, particularly between the 5 and 15 mm positions. However, the computed coefficients were still high, representing a strong correlation, thus suggesting that both TAD and CalTAD can be used as predictors of cut-out for the inferior positioning of the screw, even though they present a weaker correlation when compared with the central geometries. Finally, taking into consideration the eight geometries, a negative coefficient was found for TAD. This can be explained by an overall increase of TAD from the central to inferior models, whereas the computed volume decreased from the central to the inferior geometries. This opposite trend led to a negative correlation between TAD and the risk of cut-out. However, considering that the computed coefficient magnitude was smaller than 0.3, the correlation is considered to be negligible [30]. Considering that for CalTAD there is no significant difference between the central and inferior models, the impact of the volume reduction is smaller, keeping a positive correlation with the volume susceptible to yielding. Its correlation coefficient was 0.48, representing a low-moderate relationship with the risk of cut-out. Considering all the information, the obtained results suggest that TAD and CalTAD should only be used as predictors of cut-out for specific regions in separate, instead of being compared across the full range of possible positions of the femoral head.

Although the findings of this work may give indications to orthopaedic surgeons about the recommended position for the placement of the screw, further studies are required to strengthen the knowledge regarding this issue and address some of the limitations of this work. This study used only one bone model, specific to the subject, and the differences in bone anatomy or material properties were believed to not have great impact on the results. However, further studies using a larger number of femurs should be carried out to increase the confidence in the results. Additionally, it would be useful to compare the results obtained for femurs of patients with different genders. Regarding the loading conditions, the use of 8 loads strengths the model used in this study. Nevertheless, the addition of more loads considering other regions of the proximal femur would allow a closer approximation to the in-vivo conditions of this bone. Furthermore, the evaluation of more load cases, especially of daily activities, would be beneficial for this work. Regarding bone properties, the density distribution used in this study corresponds to a 38-year-old patient which is likely to present better bone quality than older people. Being the elderly the group of people that most suffers trochanteric fractures, future studies should use lower densities to simulate their bone properties. Finally, bone damage and cut-out were not actually simulated. Like in previous computational studies [8,9], the risk of cut-out was assumed to be related to the volume of bone presenting larger compressive strains, in magnitude, than the yield strain of the human bone.

5. Conclusion

The main goal of the present work was to find the best position to place the femoral head screw to reduce the risk of cut-out, which was found to be in the inferior region at a 10 mm distance from the surface. Additionally, the results obtained in this study revealed that the position of the screw in the medial-lateral direction of the central region is not relevant for the prevention of cut-out. The contact region between the fragments was found to be the principal location with damaged bone, representing the region that most likely contributes to the cut-out effect. Regarding the measurement techniques, the applicability of TAD and CalTAD was tested and a possible correlation with the risk of cut-out was found. However, the predictive value of both techniques is stronger when they are used only to compare positions in the same region of the femoral head. Comparing the two techniques, the results showed that CalTAD seems to be a better predictor of cut-out than TAD. Overall, the results of this study regarding the position of the implant are coherent with previous computational analyses and are expected to provide further insight into the best position for the femoral head screw placement.

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References

1. Helwig P, Faust G, Hindenlang U, Hirschmüller A, Konstantinidis L, Bahrs C, et al. "Finite element analysis of four different implants inserted in different positions to stabilize an idealized trochanteric femoral fracture". *Injury*. 2009, vol. 40, no. 3, pp. 288–95.
2. Bartoska R, Baca V, Horak Z, Hrubina M, Skala-Rosenbaum J, Marvan J, et al. "The importance of intramedullary hip nail positioning during implantation for stable pertrochanteric fractures: biomechanical analysis". *Surg Radiol Anat*. 2016, vol. 38, no. 5, pp. 577–85.
3. Lee C, Su K, Chen K, Pan C, Wu Y. "Impact of tip – apex distance and femoral head lag screw position on treatment outcomes of unstable intertrochanteric fractures using cephalomedullary nails". *J Int Med Res*. 2018, vol. 0, no. 0, pp. 1–13.
4. Tsai S, Lin CJ, Tzeng Y, Lin C. "Risk factors for cut-out failure of Gamma3 nails in treating unstable intertrochanteric fractures : An analysis of 176 patients". *J Chinese Med Assoc*. 2017, vol. 80, no. 9, pp. 587–94.

5. Panagopoulos A, Kyriakopoulos G, Anastopoulos G, Megas P, Kourkoulis SK. "Design of improved intertrochanteric fracture treatment (DRIFT) study: Protocol for biomechanical testing and finite element analysis of stable and unstable intertrochanteric fractures treated with intramedullary nailing or dynamic compression screw". *J Med Internet Res*. 2019, vol. 8, no. 7, pp. 1–14.
6. Koyuncu Ş, Altay T, Kayalı C, Ozan F, Yamak K. "Mechanical failures after fixation with proximal femoral nail and risk factors". *Clin Interv Aging*. 2015, vol. 10, pp. 1959–65.
7. Karapinar L, Kumbaraci M, Kaya A, Imerci A, Incesu M. "Proximal femoral nail anti-rotation (PFNA) to treat peritrochanteric fractures in elderly patients". *Eur J Orthop Surg Traumatol*. 2012, vol. 22, no. 3, pp. 237–43.
8. Lee PY, Lin KJ, Wei HW, Hu JJ, Chen WC, Tsai CL, et al. "Biomechanical effect of different femoral neck blade position on the fixation of intertrochanteric fracture: A finite element analysis". *Biomed Tech*. 2016, vol. 61, no. 3, pp. 331–6.
9. Goffin JM, Pankaj P, Simpson AH. "The importance of lag screw position for the stabilization of trochanteric fractures with a sliding hip screw: A subject-specific finite element study". *J Orthop Res*. 2013, vol. 31, no. 4, pp. 596–600.
10. Valentini R, Martino M, Piovan G, Fabrizio G De, Fancellu G. "Proximal cut-out in pertrochanteric femural fracture". *Acta Biomed*. 2014, vol. 85, no. 2, pp. 144–51.
11. Bojan AJ, Beimel C, Taglang G, Collin D, Ekholm C, Jönsson A. "Critical factors in cut-out complication after gamma nail treatment of proximal femoral fractures". *BMC Musculoskelet Disord*. 2013, vol. 14, no. 1, pp. 1–9.
12. Hsueh KK, Fang CK, Chen CM, Su YP, Wu HF, Chiu FY. "Risk factors in cutout of sliding hip screw in intertrochanteric fractures: An evaluation of 937 patients". *Int Orthop*. 2010, vol. 34, no. 8, pp. 1273–6.
13. Lopes-Coutinho L, Dias-Carvalho A, Esteves N, Sousa R. "Traditional distance “tip-apex” vs. new calcar referenced “tip-apex” - which one is the best peritrochanteric osteosynthesis failure predictor?". *Injury* [Internet]. 2020, vol. 51, no. 3, pp. 674–7. Available from: https://doi.org/10.1016/j.injury.2020.01.024
14. Caruso G, Bonomo M, Valpiani G, Salvatori G, Gildone A, Lorusso V, et al. "A six-year retrospective analysis of cut-out risk predictors in cephalomedullary nailing for pertrochanteric fractures: Can the tip-apex distance (TAD) still be considered the best parameter?". *Bone Jt Res*. 2017, vol. 6, no. 8, pp. 481–8.
15. Konya MN, Verim Ö. "Numerical Optimization of the Position in Femoral Head of Proximal Locking Screws of Proximal Femoral Nail System; Biomechanical Study". *Balkan Med J*. 2017, vol. 34, no. 5, pp. 425–31.
16. Andruszkow H, Frink M, Frömke C, Suntardjo S, Krettek C, Hildebrand F. "Tip apex distance, hip screw placement, and neck shaft angle as potential risk factors for cut-out failure of hip screws after surgical treatment of intertrochanteric fractures". *Int Orthop*. 2012, vol. 36, no. 11, pp. 2347–54.
17. Synthes D. "PFNA. Proximal Femoral Nail Antirotation: Surgical Technique". pp. 1–88. Available from: http://synthes.vo.llnwd.net/o16/LLNWMB8/INT Mobile/Synthes International/Product Support Material/legacy_Synthes_PDF/DSEM-TRM-0714-0120-3_LR.pdf
18. Spitzer V, Ackerman MJ, Scherzinger ANNL, Whitlock D. "The Visible Human Male: A Technical Report". *J Am Med Informatics Assoc*. 1996, vol. 3, no. 2, pp. 118–30.
19. Schileo E, Taddei F, Malandrino A, Cristofolini L, Viceconti M. "Subject-specific finite element models can accurately predict strain levels in long bones". *J Biomech*. 2007, vol. 40, no. 13, pp. 2982–9.
20. Knowles NK, Reeves JM, Ferreira LM. "Quantitative Computed Tomography (QCT) derived Bone Mineral Density (BMD) in finite element studies: a review of the literature". *J Exp Orthop*. 2016, vol. 3, no. 36, pp. 1–16.
21. "Titanium Alloys - Ti6Al7Nb Properties and Applications" [Internet]. [cited 2020 Jun 9]. Available from: https://www.azom.com/article.aspx?ArticleID=2064
22. Li J, Wang M, Li L, Zhang H, Hao M, Li C, et al. "Finite element analysis of different configurations of fully threaded cannulated screw in the treatment of unstable femoral neck fractures". 2018, vol. 3, pp. 1–9.
23. Heller MO, Bergmann G, Kassi JP, Claes L, Haas NP, Duda GN. "Determination of muscle loading at the hip joint for use in pre-clinical testing". *J Biomech*. 2005, vol. 38, no. 5, pp. 1155–63.
24. Kopperdahl DL, Keaveny TM. "Yield strain behavior of trabecular bone". *J Biomech*. 1998, vol. 31, no. 7, pp. 601–8.
25. Riggs BL, Melton LJ, Robb RA, Camp JJ, Atkinson EJ, Peterson JM, et al. "Population-based study of age and sex differences in bone volumetric density, size, geometry, and structure at different skeletal sites". *J Bone Miner Res*. 2004, vol. 19, no. 12, pp. 1945–54.
26. Boese CK, Jostmeier J, Oppermann J, Dargel J, Chang DH, Eysel P, et al. "The neck shaft angle: CT reference values of 800 adult hips". *Skeletal Radiol*. 2016, vol. 45, no. 4, pp. 455–63.
27. Asala SA. "Sex determination from the head of the

femur of South African whites and blacks". *Forensic Sci Int*. 2001, vol. 117, no. 1–2, pp. 15–22.

28. Baumgaertner MR, Curtin SL, Lindskog DM, Keggi JM. "The value of tip-apex distance in predicting failure of fixation of peritrochanteric fractures of the hip". *J Bone Jt Surg*. 1995, vol. 77, no. 7, pp. 1058–64.
29. Fujii T, Nakayama S, Hara M, Koizumi W, Itabashi T, Saito M. "Tip-Apex Distance Is Most Important of Six Predictors of Screw Cutout After Internal Fixation of Intertrochanteric Fractures in Women". *JBJS Open Access*. 2017, vol. 2, no. 4, pp. e0022.
30. Mukaka MM. "Statistics corner: A guide to appropriate use of correlation coefficient in medical research". *Malawi Med J*. 2012, vol. 24, no. 3, pp. 69–71.