The prevention of penetration of unidentified screw of femoral neck fracture during the operation

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Research

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Abstract

Background

Screw internal fixation is one of the main surgical procedures for femoral neck fractures. Routine intraoperative fluoroscopy is hard to identify screw penetration, which becomes one of the important factors of postoperative hip pain and postoperative complications.

Methods

Collect and analyze the intraoperative and postoperative imaging data of patients with internal fixation. Using geometric methods and analysis of anatomical characteristics, we explored the best imaging angle where the screw penetration was not found in the conventional 2D images of the anterior and lateral view during the operation, so that it can be determined whether there is screw penetration by taking a certain angle during the operation.

Results

The unrecognized screw penetration rate during the operation was 25%, 5% penetrated from the back of the femoral head, and 20% penetrated the femoral neck part and then entered the head. The unrecognized screw of the femoral head is caused by the intersection of the anterior and lateral projection to form the Steinmetz solid. The study found that the special photographic orientation $\theta=90°—\arctan(M_1O'/M_2O')$. For the screw penetration of the femoral neck, the probability of occurrence in different areas of the femoral neck is 10.5% of the front superior part, 44.2% of the front inferior part, 28.6% of the back superior part, and 16.8% of the back inferior part. The best shooting directions of the front superior,front inferior, back superior, and back inferior through which the detection screw passes are the positive position ,35.8° to the tail side, 70° to the head side, 46.3° to the head side, and 40.5° to the tail side.

Conclusion

It is important to avoid unrecognized screw penetration during the operation. In this study, it was concluded that a certain angle was taken during the operation to determine whether there was screw penetration, which significantly reduced the incidence of screw penetration of the femoral head and femoral neck.

Introduction:

High-energy violent injuries tend to cause proximal femoral capsular fractures among young people, which accountfor 3% of hip fractures [1, 2].For young adults, closed reduction with a screw fixation is the standard treatment for femoral head fracture.This operation usually uses three screws for fixation, which always shows good results in mini-invasive and early rehabilitation and has certain advantages [3, 4].The postoperative effect of internal fixation is generally affected by many factors, including reduction situation, internal fixation position, fixation time and other factors. In this operation, the length of screw implantation is considered as the key factor to determine the stability of reduction and the maintenance of reduction.According to biomechanical studies, the ideal implant depth is still controversial, and appropriate screw length can improve the fixation force. Brown et al. [5] believe that when the screw tip is more than 12 mm away from the subchondral surface, the failure rate of screw fixation will increase.Although the short distance between a screw tip and the femoral head edge (tip to edge distance, or TED) is recommended, being very close to the subchondral surface increases the incidence that screws penetrate the femoral head.During the operation, unrecognized screws may not only cause the limitation of the hip joint movement and pain, but also affect the blood supply of subchondral bone, resulting in necrosis.In addition, the pressure of articular cartilage on subchondral bone caused by joint damage is a potential risk factor for osteonecrosis [6].

In a study involving 395 patients, Gurusamiy et al. [7] found that reduced lateral screw distribution was associated with an increased risk of fracture nonunion.Therefore, in order to obtain greater strength and lower nonunion rate, we will stick cortical screws as much as possible. Intraoperative fluoroscopy is still the most commonly used method of screw placement navigation. Due to insufficient information provided by 2D images, On the anterior and lateral radiographs, the screw may be in the proper position, but actually it penetrates the femoral neck cortex, and the surgeon would think that such a dangerous screw placement position is a stable position.Karray et al. [8] have described the penetration of unrecognized screws in joints, and they believe that the penetration rate of unrecognized screws during surgery is 8% and that of unrecognized screws at the back of the neck is 10%. They also believe that the risk of penetration varies according to different fracture types. The other case is that the screw penetrates the femoral neck and then enters the head (IN-OUT-IN), as shown in Fig. 1. However, there is no objective, reproducible and reliable method for intraoperative verification of cannulated screws penetrating the femoral head and neck.

Methods:

Patients

We collected the data of 20 patients who underwent cannulated screw fixation for femoral neck fracture in the Second Hospital of Shanxi Medical University from March 2017 to August 2019, including intraoperative and postoperative anterior and lateral images.postoperative CT (Computed tomography) and other imaging data, and conducted a correlation analysis.

Material

We recorded CT data from the proximal femur of an adult male. All studies were performed by a 64-slice helical computer graphics scanner (GE).The data were fed into Mimics20 (Materialise, Leuven, Belgium) to reconstruct the 3D bone structure of the proximal femur, create the anterior and lateral views of the proximal femur, and then set the image opacity to 50% to convert to AP(anterior projection) and LP(lateral projection), and the four Windows were synchronized.At the same time by adjusting the position to fit out the axial photography map.Analysis was performed using the pixel and Angle measurement tool in Photoshop CS4 (Photoshop, Adobe, USA).To simplify the geometric analysis, we treat the femoral head as a sphere.

The best photographic angle to detect screw puncture in femoral head

In the process of internal fixation of femoral neck fracture with hollow screw, we can only rely on intraoperative anterior and lateral X-ray photography to evaluate the spatial position of the screw, while the image can only display 2D information of 3D objects, and the projection of femoral head on the anterior and lateral position is bound to form a "shadow part" [9].The femoral head is reduced to a sphere, and the anterior and lateral plates are projections of two cylindrical images, and the overlap between two identical vertically intersecting cylinders forms a SS (Steinmetz solid).In the anterior and lateral images, the screws obviously located in the femoral head must be located in the SS, but not necessarily in the femoral head itself. The femoral head is an intramural sphere in the SS, thus causing the insertion of undetected screws**.Fig. 2**

In this study, geometric derivation was used to obtain a special photographic angle that can find the femoral head is cut off by screw tip through standard anterior and lateral images.The anterior images of the hip joint is that the ray is perpendicular to the coronal plane of the human body. the lateral view is that the ray is located on the coronal plane of the human body and is perpendicular to the axis of the femoral neck. and the C-arm was rotated on the axis of the femoral neck. $TOD=\frac{Da}{Dm}\times TODm$ (TOD is the actual distance from the screw tip to the femoral neck axis, TODm is the distance from the screw tip to the femoral neck axis measured on the image, Da is the actual diameter of the screw, and Dm is the screw diameter measured on the image).In order to ensure that the femoral head is found when the screw tip is slightly cut out, the best photographic angle should be the cutting direction of the tip on the femoral head surface.

The screw can only be inserted out of the femoral head from the four regions at the top of the femoral neck axis, namely the front superior, front inferior, back superior, and back inferior regions.Set the center of the femoral head sphere as O and the tip of the screw as point M, then make a plane S through point M, which is perpendicular to the anterior and lateral images. S is also the projection plane of the axial images In the anterior images, the projection of point M at the tip of the screw was set as point M_1, and pass the center of the circle (center of the sphere) to make the femoral neck axis L_1.Make a perpendicular line from point M_1 to L_1 and intersect at point O'. Therefore, points M, M_1 and O 'were all in the plane S.Similarly, in the lateral photograph, the projection of point M is set as $M_{2.}$ Pass the center of the circle (center of the sphere) to make the femoral neck axis $L_{2.}$Then make a perpendicular line from point M_2 to L_2 and intersect at point O ".By magnifying the correction formula, the anterior and lateral images are combined, so O "is O' and L_2 is L_1, while points M, M_1, M_2 and O 'are all in plane S, and the four points can form a rectangle, and the length of M_1O' and M_2O 'can be measured intraoperatively.Meanwhile, the trajectory of the C-arm is parallel to plane S.Therefore, We can use mathematical algorithms in this plane and use the trigonometric function to calculate the tangent direction of M point on the sphere. The angle in this direction is the photographic angle that can find the unrecognized screw, as shown in **Fig. 3**.

The best photographic angle to detect the breakthrough of femoral neck screw

In this study, the anatomical structure of the femoral neck was analyzed and the anatomical characteristics were used to evaluate the position where the screw was most likely to go out of the femoral neck and the relatively safe area, and then to calculate the photographic angle with a high probability of finding the screw out.

After fitting of the proximal femur of a 3D image space rotation, respectively create a standard is AP and LP image, then create a projection image along the femoral neck axis (ie, the axial view of the femoral neck).In AP, make a straight line that is parallel to the axis of the femoral neck at the upper and lower bends, which are the upper and lower boundaries (a, b), in the LP, make a straight line parallel to the axis of the femoral neck at the front and back bends, which are the upper and lower boundaries (c, d) ,as shown in **Fig. 4A B .**When the screw exceeds either limit, it can be captured in the intraoperative anterior and lateral view. Therefore, the position of the screw that is not found in the anterior and lateral view can only appear in the area of the defined non-femoral neck section.

In the axial view,the projection of the femoral neck can be clearly observed and depicted.The farther away from the center, the more likely the screw is to be pierced.So the closer the screw is to the cortex in the frontal and lateral view, the more likely it is to be pierced.Using image processing software (photoshopcs4) to analyze axial photography figure, it can be find that a rectangle Z is enclosed by four straight lines a, b, c, d, and the axial projection of the femoral neck is the safe area for screw placement (Z_1), and outside of the projection area of screw cutout danger zone (Z_2). Z_2 can be divided into four areas:FS(front superior), FI(front inferior), BS(back superior), and BI(back inferior)**,** as shown in **Fig.4C**.Then use the number of pixels in photoshopcs4 to calculate the area and proportion of different areas (set the resolution to 300 pixels).In this way, the proportion of different regions in rectangle Z can be obtained to indicate the cutting risk of different regions.In addition, through the 3D reconstruction of axial view, we found that there are different cut angles in different areas of the femoral neck, so we can use the anatomical features of the femoral neck to test whether there is screw penetration: convert the axial view into a plane and then draw the tangents in different areas, finally use the angle measurement tool in PS to measure the tangents.Therefore, Therefore, it can be obtained by detecting the tangent angles of screws in different areas.

Results:

Analysis of clinical case

The collected data of 20 patients were analyzed. with an average age of 41 years (20–63 years).Among them there are 12 males and 8 females; 8 cases of them are high-energy injuries contuse and 12 cases are low-energy injuries (falls); 2 cases were instrument panel injuries (combined with ipsilateral femoral shaft fractures), 18 cases were simple femoral neck fractures; 13 cases on the left side and 7 cases on the right side; intraoperative and postoperative X-rays showed that the screws were all in the femoral head and neck. Postoperative CT identified joint penetration that caused hip joint pain and movement limitation. It showed that the penetration rate of femoral neck fracture screw was 25%, and 1 case (5%) was from behind the femoral head 4 cases (20%) penetrated through the femoral neck and then entered the head, as shown in Fig. 1.

The best photographic angle to detect screw puncture in femoral head

Through the mathematical algorithm, in the plane formed by M, M_1, M_2, O ', a straight line passing through point M and perpendicular to O'M is the desired tangent direction.Set inganterior direction to 0° and lateral direction to 90°,then the photography position that can find the screw θ = 90 ° - arctan (M_1O '/ M_2O') (M_1O'and M_2O' are the distances from screw tips to the axis of the femoral neck in the anterior and lateral photography after correction, respectively) (Note: arctan is the basic arctangent function, and the intraoperative assistant can use a simple calculator to find out in one step)If the screw is located in the anterior superior and posterior inferior region of the femoral head, the anterior view will rotate θ° to the caudal side.If the screw is located in the anterior inferior and posterior superior femoral head, the positive view rotates θ° to the head.Therefore,when it is suspected that the tip of the screw has penetrated the femoral head during the operation, additional photography in this direction is added after the anterior and lateral photography to determine whether there is an unidentified screw penetration.

The best photographic angle to detect the puncture of femoral neck screw

During the study of the optimal photographic angle of femoral neck screw puncture, PS pixel points were calculated, and the Z pixel points were 1108604, 267112, 27984, 117967, 76485 and 44783 respectively.Therefore, it can be concluded that the risk of femur head resection (Z_2) is 24.1%.Among the four regions, FS is 10.5%, FI is 44.2%, BS is 28.6%, and BI is 16.8%. Among them, FI and BS are the highest. So special attention should be paid to the position of screws in thefront inferior and back superior quadrant during the operation.Among the twenty patients we followed up, there were four patients with femoral neck screw insertion (IN-OUT-IN), among which two patients were located in FI, one in BS and one in BI, which were basically similar to the axial view measurement results.For tangent angles in different regions, FS is 35.8°, FI is 70°, BS is 46.3° and BI is 40.5°. So the tangential orientation of the area which the anterior and lateral introperative view near to can be used to detect whether screw penetration has occurred.Therefore,when the anterior radiograph was 0°, the best photographic angle to check whether there is a screw penetration in the FS area is the anterior radiograph and rotated 35.8° to the caudal. The same, FI was rotated 70° to the caudal position, BS was rotated 46.3° to the caudal position, and BI was rotated 40.5° to the caudal position.Of course, the more directions you have, the more likely you are to see unrecognized screws in the anterior and lateral views.

Discussion:

In recent years the rapid development of the transportation cause the rising of youth femoral neck fracture incidence, and screw internal fixation operation has become a main treatment. Under the 2D fluoroscopic images of the anterior and lateral during the operation, the 3D information cannot be fully displayed, which will cause the screw to penetrate the femoral head and femoral neck without knowing it. And the unidentified screw penetration is a common complication of this internal fixation method, which can cause obvious limitations, hip pain, osteoarthritis, femoral head necrosis and so on.The results of the clinical data we collected on intraoperative unidentified screw puncture were similar to the intraoperative X-ray findings of 30 patients with femoral neck fracture evaluated by Hernigou et al. [10].At the same time, screw penetration is bound to cause the destruction of femoral neck cortical bone and significantly reduce its stability. Khoo et al.[11] believed that the integrity of posterior femoral neck cortical bone significantly affects the incidence of femoral head necrosis.In addition, the metaphyseal lateral artery is the main source of blood supply to the femoral head, accounting for about 77% and providing 2/3 of the blood supply to the lateral and central femoral head.This artery is issued by the posterior superior support band derived from the medial femoral circumferential artery and is positioned above the posterior neck of the femur. Therefore, screw insertion penetrating the risk area of the femoral neck (especially the posterior superior area) causes iatrogenic injury, damages the blood supply of the femoral head, and leads to necrosis of the femoral head [12, 13].Therefore, it is very important to avoid screws penetrating femoral head and neck during the operation.

In general, both intraoperatively and postoperatively, anterior and lateral X-ray projections are limited and all screw penetration cannot detect all screw penetrations.Scott et al. [14] reported a case of hip joint pain with unknown causes.(In the case no screw perforating out of the femoral head was found on the anterior and lateral X ray. Subsequently, the inverted rotation of the contralateral pelvis 25° was adopted for the imaging, and the internal fixation was found to be perforated out of the femoral head.Kumar et al. [15] believed that there was a linear relationship between TAD (tip-apex distance) and hip joint rotation, which could predict the risk of screw perforation, but TAD was not an effective detection method since not all screws were pushed out through the femoral head.Nooredee et al. [16] reviewed 50 cases of internal fixation of hip fractures and found that up to 8% of patients may have unrecognized joint penetration.They recommend that the screw should be placed only two-thirds of the way through the center of the femoral head to prevent penetration.Mao et al. [17] proposed an appropriate TED (Tip to edge distance) (TED = 7 mm) to reduce the risk of femoral head puncture by analyzing the geometric basis of unrecognized femoral head screw puncture, which made the risk close to zero.However, for the screw internal fixation for femoral neck fracture, the tip of the screw should be less than 5 mm of the subchondral bone to improve the fixation strength.In addition,when the fracture line is at a high position, in order to make the screw thread cross the fracture line, it is difficult to achieve TED = 7 mm. Of course, intraoperative CT can solve this problem well, but the radiation dose to patients and surgeons will increase significantly.In addition, intraoperative CT technology is still limited in primary hospitals.

In our study, for the unidentified screw through the femoral head, it is found through spatial geometry that the projection of the sphere in the anterior and lateral position is a Steinmetz solid which is larger than the sphere. Making use of the geometry algorithm to find out the photography direction of screw penetration. Therefore, take a certain angle during the operation to can determine whether there is an unidentified screw penetration and significantly reduce the incidence of screw go out. At the same time, it can also significantly reduce the exposure number.For the unrecognized IN-OUT-IN, 3D image processing software was used to analyze the anatomical structure and axial view of the femoral neck. According to its anatomical characteristics, relatively safe area and the position where the screws were most likely to go out of the femoral neck were evaluated.Then the photographic angle with a high probability of finding the screw penetration was obtained.However, our method still have some shortcomings,One is to treat the femoral head as a sphere;Secondly, the anterior and lateral position is not standard, and the view may not form a standard right angle.In addition, due to the influence of anatomical factors, the photographic angle of femoral neck is not very accurate.Therefore, in order to prevent the occurrence of unrecognized femoral head and neck screw puncture, this method can be used for intraoperative confirmation and reduce the number of exposures.

Conclusion:

To sum up, through analysis of geometric methods and anatomical characteristics, this experiment explored the optimal photographic angle of screw puncture that was not found in the 2D images of the regular anterior and lateral position during the operation, which could guide the addition of a certain angle photography during the operation to determine whether there was screw puncture, and significantly reduce the incidence of screw puncture through the femoral head and neck.

Abbreviations:

2D: two-dimensional;3D:three-dimensional; TAD:Tip-apex distance;CT:Computed tomography;AP:anterior projection;LP:lateral projection; SS:Steinmetz solid;TOD:the actual distance from the screw tip to the femoral neck axis;TODm:the distance from the screw tip to the femoral neck axis measured on the image;Da is the actual diameter of the screw; Dm:the screw diameter measured on the image; FS:front superior;FI:front inferior;BS:back superior;BI:back inferior; TED:Tip to edge distance the image;

Declarations:

Availability of data and materials

All data generated or analyzed during this study are included in this published article.

Ethics approval and consent to participate

Our study has been approved by the Ethics committee of Second hospital of Shanxi Medical University.

Consent for publication

Consent for publication was obtained from all participants.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

XX and JB collected the samples and performed the experiment.JL and XW performed the statistical analysis. XX and XL prepared the manuscript. XL and JB designed the experiment. All authors read and approved the final manuscript.

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Figures

Figure 1

Clinical data of unidentified screw penetration during the operation

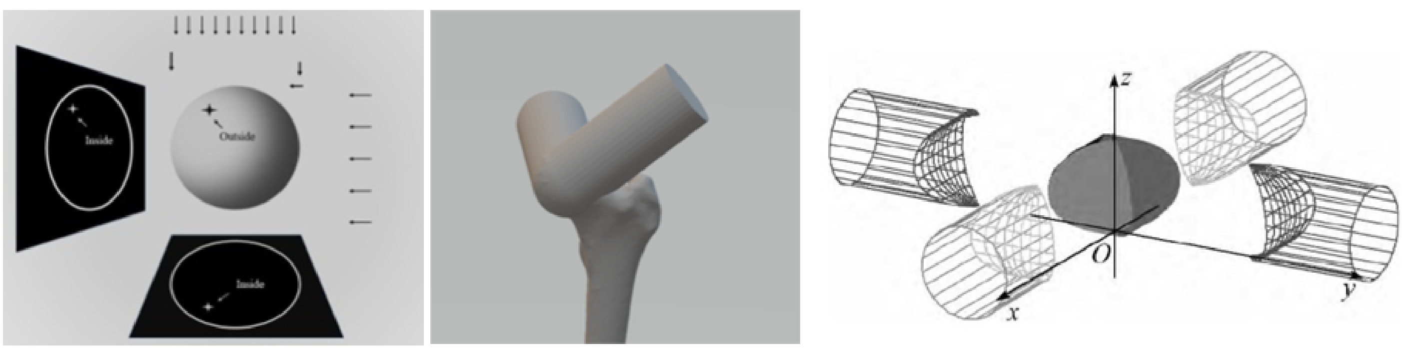

Figure 2

A is the visual blind zone formed by the femoral head in the lateral view; B and C are the overlapping parts between two identical vertical intersecting cylinders forming the Steinmetz entity, and the femoral head is an inscribed ball

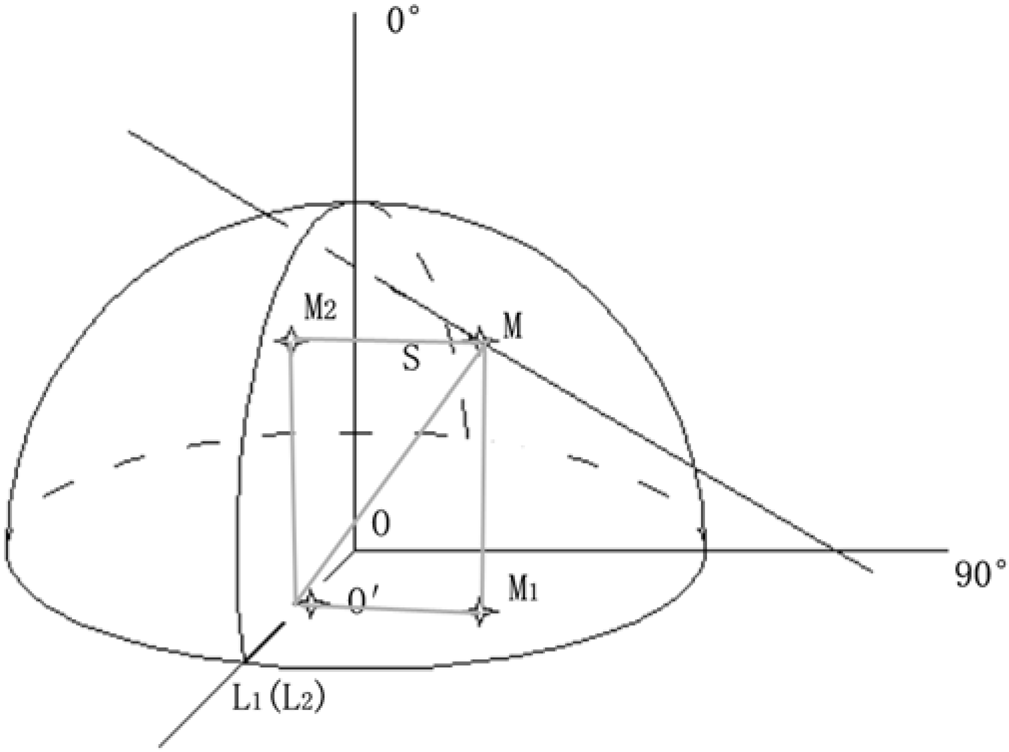

Figure 3

The angle in this direction is the photographic angle that can find the unrecognized screw

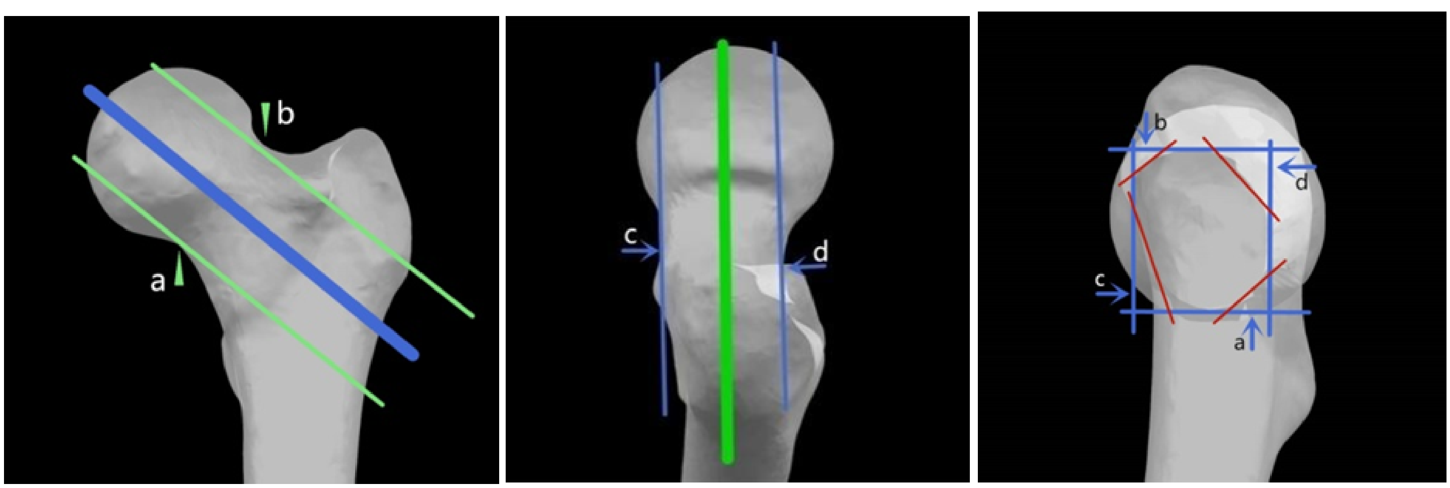

Figure 4

anterior view, lateral view and Axial view of the proximal femur