Optional Entry Point for Retrograde Femoral Nailing: An Anatomical Study Using the Reverse Engineering Method

Nattapon Chantarapanich PhD*, Banchong Mahaisavariya MD**,
Kriskrai Sitthiseripratip DEng***, Pongwit Siribodhi PhD****

* Department of Mechanical Engineering, Faculty of Engineering, Kasetsart University, Chonburi, Thailand
** Department of Orthopaedic Surgery and Rehabilitation, Faculty of Medicine Siriraj Hospital, Mahidol University, Bangkok, Thailand
*** National Metal and Materials Technology Center (MTEC), National Science and Technology Development Agency, Pathumthani, Thailand
**** Department of Aerospace Engineering, Faculty of Engineering, Kasetsart University, Bangkok, Thailand

Objective: To investigate the optimal entry point for retrograde femoral nailing using medical imaging and reverse engineering technologies.

Material and Method: One hundred and eight adult cadaveric femurs were scanned using a computed tomography (CT) scanner. To obtain three-dimensional models, medical imaging and reverse engineering technologies were used. The insertion assessment was performed using computer aided design (CAD) software. The curve representing the mid-line in the intramedullary canal in the mid-shaft region was approximated using regression analysis. The curve was extended tangentially toward the femoral condyle, where the intersection between the curve and the condylar surface is the insertion site. The location of the insertion site was determined using the center of the anterior most of the intercodylar notch as a reference point. The measured distances were presented in medial-lateral and anterior-posterior perspectives from the reference point.

Results: Average insertion site for Thai population was 0.56 mm lateral to and 12.67 mm medial to the anterior most of the intercondylar notch. The distance measured from intercondylar notch to the insertion site in the anterior-posterior direction was not significantly different between males and females; however, a significant difference in the insertion site was found in medial-lateral directions.

Conclusion: The insertion site can be clinically approximated lying on the anterior-posterior axis, since the distance from the anterior-posterior axis to the insertion site is relatively small. The insertion site for the Thai population was found to be 12 mm anterior to the center of the anterior most of the intercondylar notch.

Keywords: Computed tomography, Reverse engineering, Insertion site, Retrograde nailing, Femoral fracture

Retrograde femoral nailing is regarded as a treatment method for managing supracondylar fractures[1-7]. The distinct advantages of using the retrograde nail technique over other fixation devices include less soft tissue damage and minimal surgical exposure[8]. One of the major issues regarding this surgical procedure is the accommodation of the retrograde nail inside the intramedullary canal. Improper alignment between intramedullary nail and canal width usually requires excessive cortical reaming during the nail insertion procedure[9,10]. Consequently, the bone may be weakened and secondary fracture may occur[11]. According to the virtual 3-D simulation shown in Fig. 1, it can be seen that different insertion points are reflected in the different locations of the retrograde nail inside the intramedullary canal. A sub-optimal insertion point can cause nail protrusion out of the cortical bone. In order to avoid an undesired post-operative result determination of the optimal insertion point must be made by the surgeon. The present study aims to identify the optimal insertion point for the retrograde nailing technique using software applications for medical imaging combined with reverse engineering (RE) and Computer Aided Design (CAD)

Correspondence to:
Mahaisavariya B, Department of Orthopedic Surgery, Faculty of Medicine Siriraj Hospital, Mahidol University, Bangkok 10700, Thailand.
Phone: 0-2419-7968
E-mail: sibmh@mahidol.ac.th

technologies. The findings of the present study will be discussed and compared, where necessary, with the results of similar studies found in the literature.

Material and Method
Femur model reconstruction
A 64-slice spiral CT scanner at the Faculty of Medicine Siriraj Hospital (Thailand) was used to digitize geometrical shapes of 108 cadaveric Thai femurs. Those data images were then digitally converted into a stack of 2-dimensional medical image slices. Slice thickness of the CT data was one millimeter in epiphysis regions and five millimeters in the diaphysis region of the femurs. The digitization technique is shown in Fig. 2. The stack of 2-D computerized medical image slices were then imported into reverse engineering (RE)

Fig. 1 Virtual simulation of retrograde nail alignment (with Zimmer Retrograde Femoral Nail diameter 10 mm) illustrating different insertion sites and outcomes (a) optimal (b) and (c) non-optimal.

software (Mimics, Materialise N.V., Belgium) for purposes of 3-D model reconstruction. In each CT image slice, the optimal grey-scale pixel array value was selected. Then, the selected pixel settings from all slices were used to reconstruct the 3-D model of femur. Fig. 3 shows one of the 3-D modeled femurs.

Identify insertion site
Based on surgical technique, the parts of the fractured femur are reduced in such a way that the fracture is re-aligned to match normal femur geometry. The 3-D femur models obtained from the reconstruction process can then assumed being the alignment after fracture reduction.
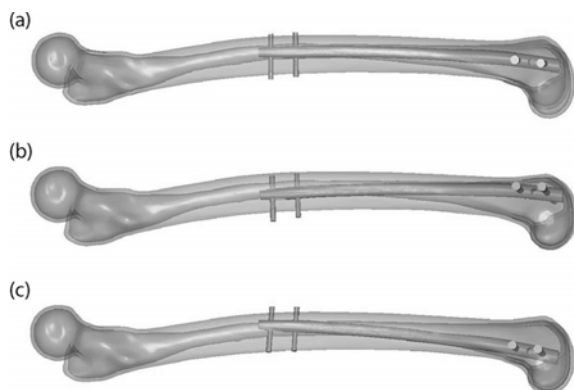
The identification of the insertion point was performed, as follows:
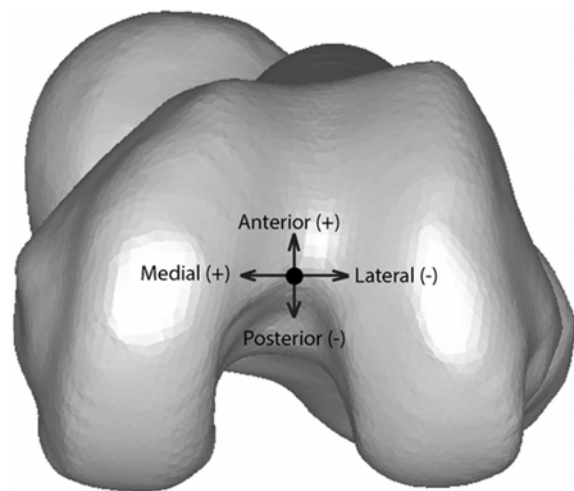#### *Step 1: Dividing the femur*
Each of the 3D femur models was divided into three portions (proximal, mid-shaft, and distal), based on the criteria described by Stephenson et al[12].

#### *Step 2: Creating the mid-line of the intra-medullary canal in mid-shaft region*
The middle line was created using a technique for finding the radius of a curvature, according to previous work by the authors[13]. A cross-section of the intramedullary canal in the mid-shaft region was extracted from the 3D model. Each cross-section was

Fig. 2 Positive/negative vectors designation.
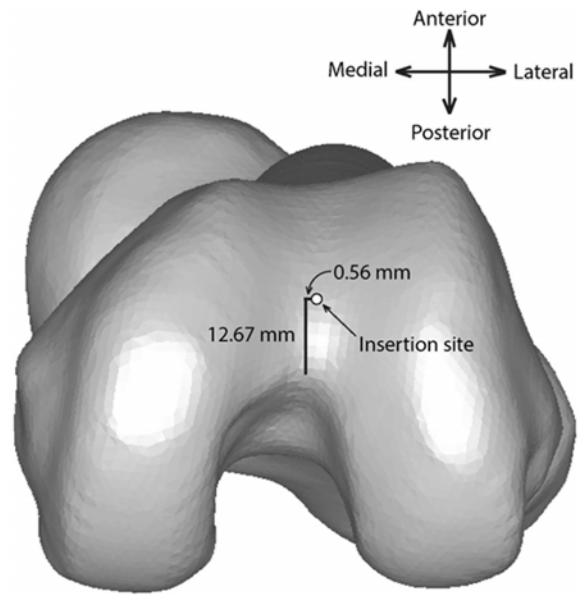
Fig. 3 Average insertion site for Thai population.

approximated to the shape of a circle. An average of the centers of the circles obtained from all of the cross-section images was then used to determine the mid-line, using the curve fitting technique.

Step 3: Mid-line extension

The mid-line was extended tangentially toward the condylar surfaces of the femur. A tangent extension was used because the mid-shaft is arched; whereas, the proximal and distal parts are more straight and approximate as no radius of curvature.

Step 4: Identifying mid-line and condylar surface intersection

The extended line was split into two portions, using the condylar line surface. The split location on the extended curve is identified as the insertion point.

Distance measurement

The condylar notch was used as an anatomical landmark for distance measurement. The condylar notch is easy to identify during the surgery due to its recognizable concave shape. The most prominent point of the concave shape is used as a reference starting point, whereas the insertion point obtained from the previous step is an end point. Positive or negative vectors in measurement were designated, as follows (see also Fig. 2):

Vector: intercondylar notch → Medial Designates as positive value (+)
Vector: intercondylar notch → Lateral Designates as negative value (-)
Vector: intercondylar notch → Anterior Designates as positive value (+)
Vector: intercondylar notch → Posterior Designates as negative value (-)

Gender effect

The two-sample t-test was used for calculating gender differences; p-value of 0.05 or less was considered statistically significant.

## Results

Average distance

The average distance measured from the intercondylar notch to the insertion site was 0.56 mm (SD = 4.17mm) in the lateral-medial direction and 12.67 mm (SD = 3.47mm) in the antero-posterior direction, as shown in Fig. 3. Fig. 4 shows the normal distribution curve of distances in lateral-medial and posterior-anterior directions for 108 femurs.

Gender difference in insertion site

As shown in Table 1, the distance measured from the intercondylar notch in males is slightly different to the same measurement in females. The distance in the medial-lateral direction is toward lateral for male and is toward medial for female. The insertion site in the anterior-posterior direction for females is more toward anterior than in males. The distance in the medial-lateral direction presents significant differences between genders ($p<0.05$), whereas no significant difference was observed in the anterior-posterior direction ($p>0.05$).

Discussion

Several previous studies[14-17] carried out
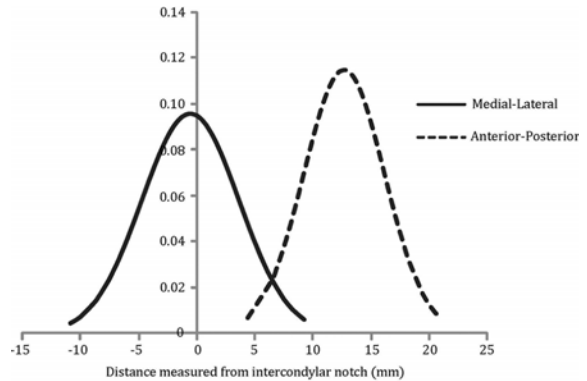
Fig. 4 Normal distribution of distance measured from the intercondylar notch in medial-lateral and anterior-posterior directions.

Table 1. Average distance measured from intercondylar notch, based on gender and p-value

Parameter	Distance ($\mu \pm$ SD)		p-value
	Male (n = 51)	Female (n = 38)	
Lateral-Medial Direction	-1.56±4.73	0.67±3.54	0.0103
Posterior-Anterior Direction	12.34±3.50	13.02±3.28	0.3437

studies to determine the insertion point by setting up their experiments similar to that of a surgical procedure. In those experiments, an/the intramedullary device was used in conjunction with radiographic images. Based on the radiographic technique, it may be accurate for study anthropometric parameters associated the complicated 3D geometry of femur[18]. A potentially more effective technique involves the use of computer engineering software, which allows the femur to be analyzed three-dimensionally. The primary technologies employed in this computerized technique are RE and CAD. RE is used to create the three-dimensional model of the femur from the CT images and CAD is used for measuring the anthropometric parameters. CT and RE technologies have been used in the study of various bone structures; examples include: femur[18,19], tibia[20], humerus[21], and skull[22]. The present study employed CAD/RE technologies to assist in determining the optimal insertion point for the retrograde nailing technique, based on the Thai population. Based on a review of the English language medical research literature by the authors of this study, no previous studies or reports have undertaken this 3-dimensional assessment method for identifying the insertion point.

In many of the previous reports, the bone and tissue specimens were cadaveric. The posterior cruciate ligament (PCL) attachment was usually selected as a starting point for referencing the insertion point. However, a soft tissue reference point is not possible in the present study because the specimens used were dry cadaveric femur. As a result, the intercondylar notch was used as a comparable anatomical location. The intercondylar notch is easily identifiable during surgery due to its concave shape.

Table 1 shows a comparison of population, materials, and methods of assessment, and obtained results between the present study and previous reports. In previous studies that used Caucasian specimens, the insertion points were varied. The closest result found in a previous report that used Caucasian specimens, as compared to this study, can be found in the findings of a study undertaken by Krupp et al[15]. Based on the Thai population, the average insertion point found in the present study is 3 mm more anterior than that found by Vaseenon et al[17].

A *p*-value was used to assess the difference in insertion point between males and females. From the statistical analysis, it can be observed that the distance in the medial-lateral direction is different, whereas the distance in the medial-lateral is not. Nevertheless, the
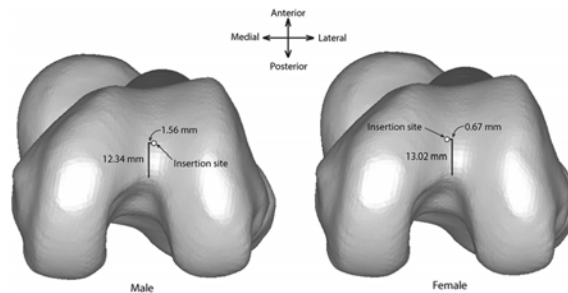
Fig. 5   The average location for the nail insertion site for male and female Thai population using the center of anterior most of intercondaylar notch as a reference point.
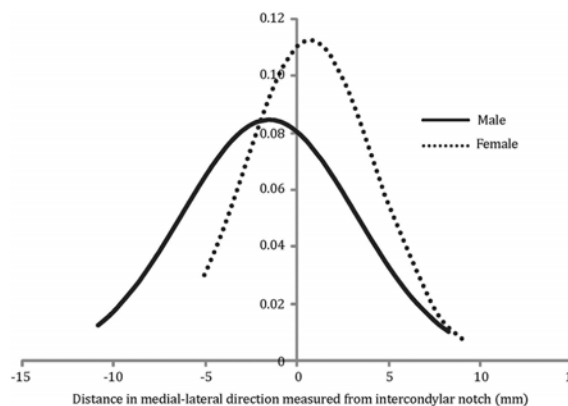
Fig. 6   Normal distribution of distance measured from intercondylar notch in medial-lateral direction for male and female population.
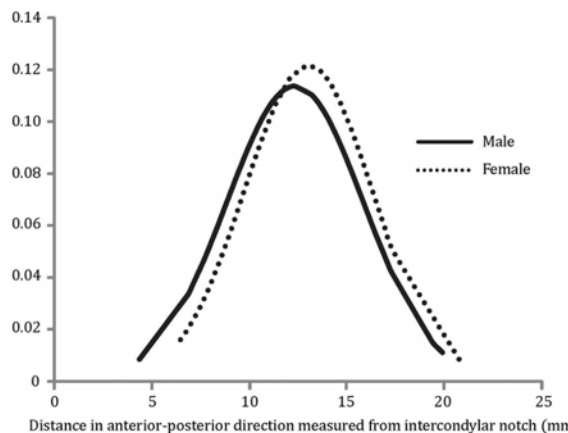
Fig. 7   Normal distribution of distance measured from intercondylar notch in anterior-posterior direction for male and female population.

distance in the lateral-medial direction is relatively small in magnitude (approximately 0.5-1.5 mm) and close to the anterior-posterior axis. As a result, the approximate

insertion site on the anterior-posterior axis is clinically acceptable.

In addition, the insertion site for the retrograde nail is located close to the distal end of the patellofemoral groove, just anterior to the PCL. This is a non-articulating surface of the knee and patellofemoral joint, and is therefore considered a safe area.

Conclusion

The present study presents the optional insertion site for retrograde femoral nail insertion in the Thai population. The results reveal that the insertion point in a medial-lateral direction for both male and female are very close to the femoral axis on the sagittal plane. However, in anterior-posterior direction, the insertion point should be positioned 12 mm anterior to the intercondylar notch.

Acknowledgement

Potential conflicts of interest

None.

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ตำแหน่งที่เหมาะสมในการสอดแกนดามยึดตรึงกระดูกต้นขาแบบย้อนทาง: การศึกษาทางกายวิภาคโดยใช้เทคโนโลยีวิศวกรรมย้อนรอย

ณัฐพล จันทร์พาณิชย์, บรรจง มไหสวริยะ, กฤษณ์ไกรพ์ สิทธิเสรีประทีป, ปองวิทย์ ศิริโพธิ์

วัตถุประสงค์: การใช้เทคโนโลยีภาพถ่ายทางการแพทย์ วิศวกรรมย้อนรอย และคอมพิวเตอร์ช่วยออกแบบ เพื่อหาตำแหน่งในการใส่แกนดามยึดตรึงกระดูกเข้าสู่โพรงกระดูก

วัสดุและวิธีการ: กระดูกต้นขาผู้ใหญ่จำนวน 108 ชิ้น ของผู้บริจาคร่างชาวไทยถูกนำมาเก็บข้อมูลลักษณะรูปทรง ด้วยเครื่องเอกซเรย์คอมพิวเตอร์ นำข้อมูลดังกล่าวมาสร้างเป็นแบบจำลองสามมิติของกระดูกต้นขา ด้วยเทคนิควิศวกรรมย้อนรอย เพื่อใช้หาตำแหน่งในการใส่แกนดามแบบย้อนทางเข้าสู่โพรงกระดูกเพื่อหาตำแหน่งดังกล่าวนี้ รูปร่างของโพรงกระดูกต้นขาส่วนกลางจะถูกนำประมาณค่าหาเส้นแกนกลาง จากนั้นเส้นจะถูกยืดเส้นออกไปทางด้าน femoral condyle ส่วนที่ผิวของกระดูกเส้นตัดกับเส้นเป็นตำแหน่งในการใส่แกนดามยึดตรึงกระดูกเข้าสู่โพรงกระดูก ซึ่งระยะในการระบุตำแหน่งในการใส่จะอ้างอิงจากจุดกึ่งกลางทางด้านหน้าของ intercondylar notch โดยระบุเป็นค่าระยะตามแกน medial-lateral และ anterior-posterior

ผลการศึกษา: ตำแหน่งในการใส่แกนดามยึดตรึงกระดูกเข้าสู่โพรงกระดูกโดยเฉลี่ยของคนไทยจะห่างจากจุดกึ่งกลางของขอบหน้า intercondylar notch ไปทาง lateral 0.56 มิลลิเมตร และไปทางด้านหน้า 12.67 มิลลิเมตร สำหรับความแตกต่างของระยะทางตามแกน anterior-posterior นั้นไม่มีนัยสำคัญทางสถิติระหว่างกระดูกต้นขาเพศชายและหญิง แต่สำหรับความแตกต่างของระยะทางตามแกน medial-lateral นั้นมีความแตกต่างอย่างมีนัยสำคัญ

สรุป: ตำแหน่งที่เหมาะในการสอดใส่แกนดามยึดตรึงกระดูกเข้าสู่โพรงกระดูกโดยเฉลี่ยของคนไทยอยู่ในแนวกึ่งกลาง notch โดยเยื้องออกจากขอบด้านหน้าของ intercondylar notch ไปทางด้านหน้า 12 มิลลิเมตร