Original Article

# An Innovative Three-Dimensional Method for Identifying a Proper Femoral Intramedullary Entry Point in Total Knee Arthroplasty

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## Abstract

**Background:** Identification of the proper femoral intramedullary (IM) access point is an important determinant of final implant position in IM-guided total knee arthroplasty (TKA). The aim of this study was to identify the optimal entry point in Chinese participants using a new three-dimensional method.

**Methods:** A series of computed tomography scans of 44 femurs in Chinese participants from October 2014 to October 2015 were imported into Mimics 17.0 software to identify the optimal entry point. The apex of the intercondylar notch (AIN) was used as the reference bony anatomical landmark to identify the proper entry point to insert the IM rod. The statistical significance was calculated on the basis of a 5% level ($P < 0.05$) using the Student's *t*-test.

**Results:** For the males, the average ideal entry point was 1.49 mm medial and 13.39 mm anterior to the AIN. The values were 1.77 mm medial and 15.29 mm anterior to the AIN in females. A significant difference was present between males and females (13.39 ± 2.46 mm vs. 15.29 ± 3.44 mm, $t = 2.124$, $P = 0.040$). When using the recommended location as the entry point for the IM rod, the mean potential error differed significantly from the femoral trochlear groove (the potential error of IM in males in coronal plane: 0.93° ± 0.24° vs. 1.27° ± 0.32°, $t = -4.166$, $P < 0.001$; the potential error of IM in males in sagittal plane: 1.40° ± 0.42° vs. 2.79° ± 0.70°, $t = -7.155$, $P < 0.001$; the potential error of IM in females in coronal plane: 0.73° ± 0.28° vs. 1.15° ± 0.35°, $t = -3.940$, $P < 0.001$; and the potential error of IM in females in sagittal plane: 1.48° ± 0.47° vs. 2.76° ± 0.83°, $t = -5.574$, $P < 0.001$). A significant difference was present between the recommended point and the point 10 mm anterior to the origin of the posterior cruciate ligament (the potential error of IM in males in coronal plane: 0.93° ± 0.24° vs. 1.53° ± 0.43°, $t = -5.948$, $P < 0.001$; the potential error of IM in males in sagittal plane: 1.40° ± 0.42° vs. 2.15° ± 0.75°, $t = -3.152$, $P = 0.003$; the potential error of IM in females in coronal plane: 0.73° ± 0.28° vs. 1.28° ± 0.42°, $t = -4.632$, $P < 0.001$; and the potential error of IM in females in sagittal plane: 1.48° ± 0.47° vs. 2.40° ± 0.93°, $t = -3.763$, $P = 0.001$).

**Conclusions:** The technique described here is an innovative method for swift, easy, and accurate access to the medullary canal during TKA, and it can optimize the position and orientation of the prosthetic components in knee arthroplasty.

**Key words:** Displacement; Femoral Intramedullary Guide; Intercondylar Notch; Total Knee Arthroplasty

## Introduction

Restoration of the mechanical axis of the lower extremity in total knee arthroplasty (TKA) is crucial for the function and long-term survival of the prosthetic components. Malalignment greater than 3° may increase the likelihood of implant failure.[1,2] Another technique for TKA is anatomic alignment, which is performed under the assumption that a TKA should replicate the native anatomic alignment of

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the joint line. However, with currently available prosthetic designs, mechanical alignment is preferable to anatomic alignment.[3]

The improvement of limb alignment has been the focus of a considerable amount of recent researches. Conventional knee arthroplasty techniques prefer intramedullary (IM) alignment to guide the distal femoral resection. Other new approaches including computer-assisted surgery (CAS) and patient-specific instrumentation (PSI) have been also recommended.[4-6] However, the IM rod is still the most commonly used instrument in TKA.[7,8]

The femoral entry point is an important determinant of the final prosthetic position when using an IM rod. Malpositioning of the entry hole may result in misalignment of the femoral cut by several degrees.[5,9-11] Some studies have suggested that the entry hole should be placed at the center of the femoral groove or several millimeters medial to it.[9,11] The apex of the intercondylar notch (AIN) was used as the reference point to identify the entry point in other studies.[9,12] Numerous surgical technique guides have recommended that the entry point should be 10 mm anterior to the origin of the posterior cruciate ligament (PCL).[12]

The purpose of this study was to identify an optimal entry point using a new three-dimensional (3-D) method. We also mimicked the IM rod insertion using the 3-D method and projected the axis of the rod to the coronal or sagittal planes to measure the potential angle instead of the frequently used mathematical model, which neglects femoral sagittal bowing.[5,11,13]

## Methods

### Ethical approval

The study was conducted in accordance with the *Declaration of Helsinki*. As a retrospective study, this study was exempt from the informed consent from patients.

### Data acquisition

We retrospectively reviewed lower extremity contrast-enhanced computed tomography (CT) scans in the Digital Imaging and Communications in Medicine (DICOM) data from the existing database in the Radiology Department of the China-Japan Friendship Hospital. From October 2014 to October 2015, many Chinese patients underwent lower extremity contrast-enhanced CT scans with a 0.625-mm thickness for the diagnosis of arteriosclerosis. We evaluated some patients' CT data for this study. Exclusion criteria included previous lower extremity surgery, pain in the knee, rheumatoid arthritis, ankylosing spondylitis, obvious varus or valgus deformity, or any disease of the femurs. In total, we analyzed 44 femurs of 22 patients (12 men, 10 women) who had a mean age of 51.7 years (range, 33–65 years). The CT data used in this research were obtained from the image database of our hospital, and no other experiments involving the participants were performed in this study.

### The proper entry point for the femur

Mimics 17.0 (Materialise, Leuven, Belgium) software was used in this research. The DICOM data were imported into Mimics 17.0 to reconstruct the 3-D femur model. The femur mask thresholds were set to cortical bone (CT, adult) for calculating polylines. Polylines of the femoral canal were obtained by polyline growing from the calculated polylines of the femur mask. The centerline of the canal polylines can be obtained through the Mimics tool, Fit Centerline. The midpoints of the cross sections at 10 cm (point 1) and 20 cm (point 2) proximal to the knee joint surface in the femur then were identified by the centerline [Figure 1]. The line (line 1) connecting the two points was deemed to be the anatomical axis of the distal femur, which is important in IM-TKA.[5] The point at which the axis intersected the distal articular surface was determined to be the proper entry point (point 3) [Figure 2a].

We defined the femoral coronal plane by the epicondylar axis and the lowest point of the lesser trochanter. Use of the epicondylar axis was logical because it essentially paralleled the center of knee rotation and was applied to the femoral rotational alignment during TKA.[14,15] The surgical epicondylar axis was identified by two points, one on the medial epicondyle (sulcus) and one on the lateral epicondyle (prominence).[16] The AIN was used as a bony anatomical landmark to identify the proper entry point [Figure 2b]. The offset of the proper entry point to the AIN on the cross section was then measured in both the medial direction (in the coronal plane) and the anterior direction (in the sagittal plane) [Figure 2c].

### Validation of potential angle error

We simulated the insertion of the IM rod using 3-D methods and projected the axis of the rod to the coronal or sagittal planes to measure potential angle error. We chose the recommended point obtained from the measured results as the entry point for the IM rod. First, we created a cylinder (radius = 4 mm, length = 20 cm) to simulate an IM rod as described in a previous report.[5] Second, the cylinder was duplicated to four rods. The rods were then placed in the medullary canal from the recommended point in four directions (medial, lateral, anterior, and posterior) relative to the epicondylar axis. The most important step was to adjust the locations of the rods to ensure that the rods were in canal polylines and as deviated from the anatomical axis as possible. This meant that the rod

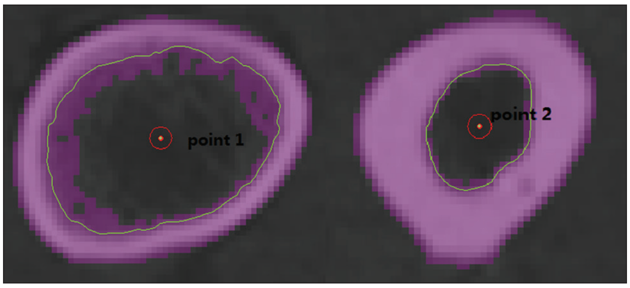


**Figure 1:** Cross sections at 10 cm and 20 cm above the knee joint surface. Point 1 and point 2 represent the center of the medullary cavity.

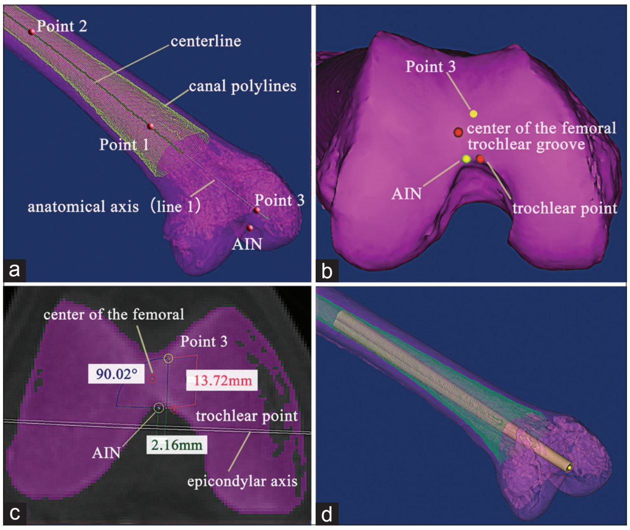


**Figure 2:** The proper entry point for the femur and the insertion of the IM rod (a) on a 3-D femur model. The line 1 connecting the two points represents the anatomic axis. The point 3 at which the axis intersected the distal articular surface was determined to be the proper entry point. (b) The AIN, the center of the femoral trochlear groove, and the trochlear point were shown on the distal articular surface. (c) The offset of the point 3 to AIN was measured in two directions. The epicondylar axis was identified by two points in 3-D model and projected in this cross section. (d) The IM rods were in the femoral canal in different directions. IM: Intramedullary; AIN: Apex of the intercondylar notch; 3-D: Three dimensional; Points 1&2: at 10 cm and 20 cm proximal to the knee joint surface in the femur.

positions were at the largest potential angle [Figure 2d]. Third, the femur, the coronal plane, point 3, line 1, and the rods were copied to 3-matic (Materialise, Leuven, Belgium). The axes of the cylinders and the anatomical axis were projected to a new sketch that was created in 3-matic, which was parallel to the coronal plane and through point 3. We then measured the maximum angle between the axis of the rod and the anatomical axis in the sketch to get the maximum potential angle error in the coronal plane [Figure 3a]. Another sketch was created that went through line 1 and was perpendicular to the coronal plane to obtain the maximum potential angle error in the sagittal plane [Figure 3b].

When the center of the femoral groove was taken as the entry point, previous researchers used a mathematical model to calculate the potential angle error, but this neglected femoral sagittal bowing.[5,11,13] In contrast, we used the 3-D method to measure the potential angle errors. In the distal cross section that contained the cortical bone of the femoral groove, the center of the circle tangential to the anteroposterior edges of the intercondylar cortical bone was deemed to be the center of the femoral trochlear groove.[5] We simulated the insertion of the IM rod through the center of the femoral groove to measure the potential angle errors using our method.

Many surgeons have chosen the point 10 mm anterior to the origin of the PCL as the entry point. Because the attachment of the PCL on the femur was so broad, it was difficult to identify the exact origin on the CT images. In an anatomical study of the PCL, the trochlear point was close to the origin of the PCL [Figure 2b].[17] Thus, the trochlear point was used as the anatomical landmark to identify the point 10 mm anterior to the origin of the PCL. The potential angle errors were then measured using the same method.

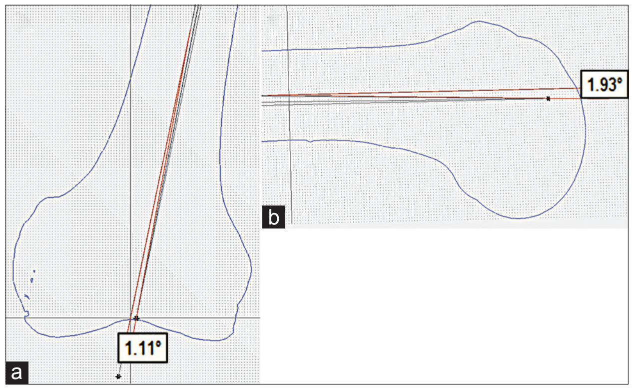


**Figure 3:** Potential angle error in different planes. (a) The maximum angle between the axis of rod and the anatomical axis was measured in the coronal plane. (b) The maximum angle between the axis of rod and the anatomical axis was measured in the sagittal plane.

### Statistical analysis

When the AIN, the epicondylar axis, the center of the femoral trochlear groove, and the trochlear point were identified and error was thought to be present, two other researchers participated in these steps to reduce the measurement error. Data are presented as mean ± standard deviation (SD). The statistical significance was calculated on the basis of a 5% level ($P < 0.05$) using the Student's $t$-test. All calculations were performed using IBM SPSS Statistics for Windows, version 19.0 (IBM Crop., Armonk, NY, USA).

## Results

### Mean value of the entry point

The entry point was 1.49 ± 0.92 mm (range, 0.32–3.76 mm) medial to the AIN and 13.39 ± 2.46 mm (range, 9.36–17.60 mm) anterior to the AIN in males. However, the entry point was 1.77 ± 1.04 mm (range, 0.24–4.45 mm) medial to the AIN and 15.29 ± 3.44 mm (range, 9.21–21.65 mm) anterior to the AIN in females. A significant difference was present between males and females [Table 1].

### Potential angle error

Because of the differences between the sexes, we adopted an entry point 1.49 mm medial and 13.39 mm anterior to the AIN in males and 1.77 mm medial and 15.29 mm anterior to the AIN in females. There were three female femurs in which we were unable to place the rod in the femoral canal when using the center of the femoral trochlear groove as the entry point because the entry points were too far from the proper points. However, when we used the recommended point or 10 mm anterior to the origin of the PCL as the entry point for the IM rod, there were two femurs (among the three samples) in which we failed to put the rod in the canal because of rather narrow medullary cavity.

When inserting the IM rod from the recommended point, the potential angle error in males was 0.93° ± 0.24°

(range, 0.44–1.45°) in the coronal plane and 1.40° ± 0.42° (range, 1.11–2.43°) in the sagittal plane. In females, the potential angle error was 0.73° ± 0.28° (range, 0.27–1.24°) in the coronal plane and 1.48° ± 0.47° (range 0.77–2.61°) in the sagittal plane. All potential angle errors were below 2° in the coronal plane and below 3° in the sagittal plane. When using the recommended location as the entry point for the IM rod, the mean potential error differed significantly from the femoral trochlear groove (the potential error of IM in males in coronal plane: $t = -4.166$, $P < 0.001$; the potential error of IM in males in sagittal plane: $t = -7.155$, $P < 0.001$; the potential error of IM in females in coronal plane: $t = -3.940$, $P < 0.001$; and the potential error of IM in females in sagittal plane: $t = -5.574$, $P < 0.001$). A significant difference was present between the recommended point and the point 10 mm anterior to the origin of the PCL (the potential error of IM in males in coronal plane: $t = -5.948$, $P < 0.001$; the potential error of IM in males in sagittal plane: $t = -3.152$, $P = 0.003$; the potential error of IM in females in coronal plane: $t = -4.632$, $P < 0.001$; and the potential error of IM in females in sagittal plane: $t = -3.763$, $P = 0.001$) [Tables 2 and 3].

## Discussion

The IM alignment rod has been widely used for the distal femoral cut in TKA. However, there are more than 10% of cases in which accurate alignment cannot be achieved (postoperative mechanical axis within 2° of neutral).[7] Errors with the IM alignment may arise from an improper entry point, improper IM rod length or diameter, or improper distal femur resection angle.[11,18] In Bertin's study,[19] the 8-mm rod fit well into 91% of measured participants, while the 10-mm rod would fit into only 40%. Thus, we choose an 8-mm cylinder to simulate an IM rod, and there was one femur that could not fit an 8-mm rod. To achieve the correct alignment, the proper entry point should be identified. This study was designed to identify an optimal entry point in TKA using an IM alignment system. The AIN was used as a bony anatomical landmark because the point could be identified easily on CT images. The AIN could be identified by cleaning osteophytes in the intercondylar notch intraoperatively.

In a radiographic study by Reed and Gollish, they considered that the entry point was an average of 6.6 mm medial to the center of the notch.[11] The center of the notch was obtained from plain radiographs and may be difficult to be identify precisely during an operation. Wangroongsub and Cherdtaweesup[12] considered that the proper entry point should be 1.5 mm medial and 12 mm superior to the top of the femoral intercondylar notch. The reference point was the same as ours, and the values were close to

**Table 1: Mean values of the femoral intramedullary entry point**

| Parameters | Male femurs (mm, $n$ = 24) | Female femurs (mm, $n$ = 20) | $t$ | $P$ |
|---|---|---|---|---|
| Medial to the AIN | 1.49 ± 0.92 | 1.77 ± 1.04 | 0.938 | 0.354 |
| Anterior to the AIN | 13.39 ± 2.46 | 15.29 ± 3.44 | 2.124 | 0.040 |

Data are presented as mean ± standard deviation. AIN: Apex of the intercondylar notch.

**Table 2: Difference of potential angle error between recommended point and the center of the femoral trochlear groove**

| Parameters | Center of the femoral trochlear groove ($n$ = 24) | Recommended point ($n$ = 24) | $t$ | $P$ |
|---|---|---|---|---|
| The potential error of IM in males in coronal plane | 1.27° ± 0.32° | 0.93° ± 0.24° | −4.166 | <0.001 |
| The potential error of IM in males in sagittal plane | 2.79° ± 0.70° | 1.40° ± 0.42° | −7.155 | <0.001 |
| The potential error of IM in females in coronal plane | 1.15° ± 0.35°* | 0.73° ± 0.28°† | −3.940 | <0.001 |
| The potential error of IM in females in sagittal plane | 2.76° ± 0.83°* | 1.48° ± 0.47°† | −5.574 | <0.001 |

Data are presented as mean ± standard deviation. *$n$ = 17; †$n$ = 18.

**Table 3: Difference of potential angle error between recommended point and the point 10-mm anterior to the origin of the PCL**

| Parameters | 10 mm anterior to the origin of the PCL ($n$ = 24) | Recommended point ($n$ = 24) | $t$ | $P$ |
|---|---|---|---|---|
| The potential error of IM in males in coronal plane | 1.53° ± 0.43° | 0.93° ± 0.24° | −5.948 | <0.001 |
| The potential error of IM in males in sagittal plane | 2.15° ± 0.75° | 1.40° ± 0.42° | −3.152 | 0.003 |
| The potential error of IM in females in coronal plane | 1.28° ± 0.42°* | 0.73° ± 0.28°* | −4.632 | <0.001 |
| The potential error of IM in females in sagittal plane | 2.40° ± 0.93°* | 1.48° ± 0.47°* | −3.763 | 0.001 |

Data are presented as mean ± standard deviation. *$n$ = 18. PCL: Posterior cruciate ligament.

our outcomes. These radiographic studies depended on 2-D radiographs that may be influenced by rotational alignment of the lower limb.

The method to identify the femoral anatomical axis and the center of the femoral trochlear groove was similar to the results obtained by Xiao *et al.*[5] However, the midpoints of the cross sections at 10 cm and 20 cm proximal to the knee joint surface in the femurs were identified by the centerline of the canal polylines rather than by close circle fitting. The rod entry point position in the coronal plane was 2.94 ± 1.12 mm (range, 0.79–4.91 mm) medial and 6.01 ± 2.09 mm (range, 2.49–9.51 mm) anterior to the deepest point of the intercondylar notch in Xiao *et al.*'s study.[5] However, use of the deepest point of the intercondylar notch in that study meant that the center of the femoral trochlear groove may have been difficult to identify precisely during an operation.

When inserting the IM rod from the recommended point, all potential angle errors were below 2° in the coronal plane and below 3° in the sagittal plane. Previous researchers calculated the potential angle errors using a mathematical model that neglected femoral sagittal bowing, which may have caused errors.[5,11,13] We measured the potential angle errors by reproducing the step of inserting the IM rod using 3-D methods and projecting the axis of the rod to the coronal or sagittal planes. To our knowledge, the method was the first to use the measurement of potential angle errors in TKA.

The neutral mechanical axis in the coronal plane is the optimal radiographic outcome to pursue in TKA. Femoral sagittal alignment is as vital as the coronal and axial alignment.[19] However, the optimal sagittal alignment and its influence on the longevity of the implants are not well understood.[8] Extension of the femoral implant is thought to create a risk of femoral notching with the anterior bone cut. If the femoral implant is in an excessively flexed position, it is possible that anterior impingement of the post may occur when a posterior-stabilized prosthesis is used.[19] Flexing the femoral implant in a cruciate-retaining TKA may increase posterior condylar offset and immediate knee range of motion.[20] Some surgeons have recommended the placement of the femoral implant in 3° flexion in the sagittal plane. When using the center of the femoral trochlear groove or 10 mm anterior to the origin of the PCL as the entry point, the IM rod often tends to be in flexion relative to the anatomical axis of the sagittal plane. If the goal is to place the femoral implant in a mildly flexed position, the distance of the entry point to the AIN should be decreased appropriately. However, the alignment parallel to the distal anatomical axis in the sagittal plane was still seen as the correct sagittal positioning of the femoral component.[5,8,12,19]

In some patients, when the IM rod was being inserted gradually, it was observed that the rod moved anteriorly at the entry hole, especially in female patients. This phenomenon has been shown to be related to femoral sagittal bowing in Chinese people and may affect the final sagittal position of the femoral component.[8] In Tang *et al.*'s study,[8] the distal femoral bowing was more profound in patients with rheumatoid arthritis and in those with a short femur. This may be one reason for the differences observed between males and females in this study. The IM guide rod should be used with caution in patients with obvious bowing.

Recently, other new approaches such as CAS and PSI have been used to improve limb alignment.[4-6] The results of CAS versus conventional TKA with regard to mechanical axis have been mixed.[6,21,22] In addition, there was no difference in functional outcomes.[23] However, the shortcomings of CAS involved difficulty with accurate identification of landmarks, increased operative time and costs, and a substantial learning curve.[24] PSI, which offers various theoretical advantages, was thought to enhance implant alignment.[25] However, the absence of proven clinical, radiographic, and cost benefits over conventional instrumentation does not support the routine use of PSI in TKA.[4] At present, the IM rod is still the most commonly used instrument in TKA.[7] It is necessary to minimize the error in femoral alignment in setting the cutting guide during TKA.

There are limitations of the present study. First, the number of participants in the study was relatively small. Second, we only considered one commonly used jig size (rod length = 20 cm, radius = 4 mm). Third, other factors such as height and overall bone length, which may have affected the results, were not taken into account. The difference between Asian and Western patients could not be assessed, so this method may be more useful for Asian surgeons. Finally, the method we used requires further intraoperative verification in the future.

In conclusion, when an IM guide rod is used during TKA, the entry point is a crucial determinant of the final prosthetic position. We recommend using the AIN as the reference landmark to identify the proper entry point in Asians. The present technique is an innovative method for swift, easy, and accurate access to the medullary canal during TKA. It might be used to optimize the position and orientation of the prosthetic components during knee arthroplasty. For experienced surgeons who often prefer no more than one method to identify the entry point, the results of this study may provide a supplementary method. When we simulated the recommended point as the entry point for the IM rod, the potential error was significantly improved.

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### Conflicts of interest

There are no conflicts of interest.

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# 一种新的确定全膝关节置换术中股骨髓内定位入针点的三维重建方法

## 摘要

**背景：**股骨髓内定位进针点的准确选择是决定全膝关节置换术最终股骨假体位置的关键因素。本研究旨在通过一种新的三维重建的方法来确定中国人群最佳的股骨进针点。

**方法：**收集自2014年10月至2015年10月期间下肢CT的数据，并将其导入软件Mimics 17.0中，通过三维重建来确定最佳的髓内定位进针点。使用髁间窝顶点来作为骨性解剖标志来确定合适的进针点。统计学分析采用*t*检验，$p<0.05$认为有统计学意义。

**结果：**对于男性受试者来说，平均的进针点位于髁间窝顶点向内1.49mm及向前13.39mm，对于女性来说则是髁间窝顶点偏内1.77mm及偏前15.29mm。男性与女性的结果之间存在统计学差异(13.39±2.46mm vs 15.29±3.44mm, $t$=2.124, $p$=0.040)。当使用推荐的进针点时，潜在的平均误差与使用股骨滑车沟中点时存在统计学差异（男性在冠状面平均的潜在误差：0.93±0.24° vs 1.27±0.32°, $t$=-4.166, $p<0.001$；男性矢状面误差：1.40 ± 0.42° vs 2.79±0.70°, $t$=-7.155, $p<0.001$; 女性冠状面误差：0.73±0.28° vs 1.15±0.35°, $t$=-3.940, $p<0.001$；女性矢状面误差：1.48±0.47° vs 2.76±0.83°,$t$=-5.574, $p<0.001$）。而推荐进针点的潜在误差与后交叉韧带止点前10mm的位置作为进针点之间也存在统计学差异(男性在冠状面平均的潜在误差: 0.93±0.24° vs 1.53±0.43°, $t$=-5.948, $p<0.001$;男性矢状面误差: 1.40 ± 0.42° vs 2.15±0.75°, $t$=-3.152, $p$=0.003; 女性冠状面误差：0.73±0.28° vs 1.28±0.42°, $t$=-4.632, $p<0.001$;女性矢状面误差: 1.48±0.47° vs 2.40±0.93°, $t$=-3.763, $p$=0.001)。

**结论：**本研究提供了一种方便、快捷、准确的确定髓内定位进针点的方法，可以使进针点更准确，从而使股骨假体位置和方向更加准确。