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Original Research

Safe Zones and Trajectory of Femoral Pin Placement in Robotic Total Knee Arthroplasty

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A B S T R A C T

Background: Robotic-assisted total knee arthroplasty may result in array pin-related complications. Lack of knowledge on ideal pin placement results in varied insertion sites and trajectory, with unknown risks to surrounding neurovascular structures.
Methods: This study included 10 lower-extremity magnetic resonance images. Images were subdivided into 6 zones of study. Zones consisted of a correlating axial image with femoral pin placement replicated by drawing a line angled 45° from the anterior to posterior reference in the anteromedial to posterolateral femoral quadrants. The distances from the pin paths to the neurovascular structures were measured.
Results: Zone 2C demonstrated femoral pin trajectory an average of 14 mm from the femoral artery/vein. In Zone 2B, proximity increased to an average of 30 mm to the femoral artery and 29 mm to the femoral vein. At Zone 1A, the popliteal artery and vein were on average 22 mm from the femoral pin, while the common peroneal nerve was an average of 21 mm. Placing pins in Zone 1A poses a high risk of injury to the genicular arteries. Women demonstrated greater proximity to neurovascular structures than men in 66% of the sites ($P < .05$).
Conclusions: This classification system for safe zones and trajectory of femoral pin placement in robotic-assisted total knee arthroplasty demonstrates that proximally, the profunda femoris and femoral artery/vein are at risk of injury, while distally, the genicular arteries, common peroneal nerve, and popliteal artery/vein are at risk. Caution should be exercised if femoral pins are inserted with an angle less than 45°, especially in women.

Introduction

The emerging popularity of technology-assisted total knee arthroplasty (TKA), particularly robotic-assisted total knee arthroplasty (RATKA), has introduced a unique set of complications when compared to conventional instrumentation [1]. The need for femoral and tibial arrays creates the potential for pin-related complications [2–5]. While increasing awareness focuses on the risk of pin-site fracture or infection, scarce literature exists on the risk of iatrogenic injury to the surrounding soft tissues due to pin placement. As such, the risk to surrounding neurovascular structures has yet to be determined.

Limited knowledge of ideal pin placement leads to varied insertion and trajectory, largely based on surgeon preference. Extensive research has been conducted on complications associated with external fixation pin sites, primarily focusing on the incidence of pin-site irritation and infection, and placing significant emphasis on preventive measures [6,7]. Among the reported complications, one notable concern is the occurrence of bone loss after pin removal, leading to the formation of a stress riser and subsequently increasing the risk of fractures [6]. However, there is a lack of studies investigating the potential damage to neurovascular structures, with limited findings restricted to case reports [8,9]. Placement of tibial array pins can be safely performed using knowledge of external fixation of the lower extremity [10].

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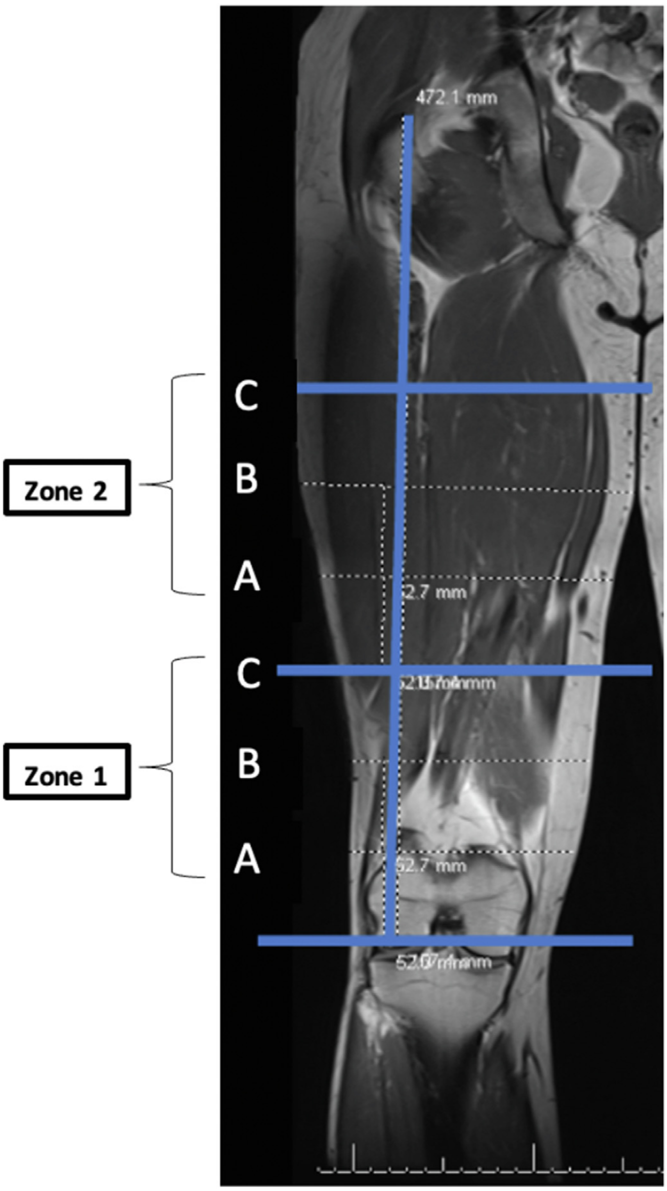

Figure 1. Coronal MRI images of a right femur divided into zones of projected femoral pin insertion sites. MRI, magnetic resonance imaging.

Insertion of the femoral array pin is typically performed from an anteromedial to posterolateral direction, which differs from conventional femoral external fixator application [11]. Avoidance of a direct anterior to posterior pin placement should be exercised as it has been demonstrated to be associated with increased periprosthetic fracture [12]. Available literature demonstrates that a high risk to neurovascular structures exists when utilizing manufacturer recommended technique for femoral array pin placement [13]. Therefore, the primary aim of our study was to measure the proximity of surrounding neurovascular structures to the projected femoral pin placement throughout the femur. Our secondary aim included analyzing the difference between sexes. We hypothesize that an increased risk to vascular structures is present proximally in the femur and to women compared to men.

Material and methods

The study included 10 lower-extremity magnetic resonance imaging (MRI) images from the hip through the knee, comprising 5 age-matched pairs of men and women. The femurs were divided into 3 equal zones by drawing a line from the greater trochanter to the knee joint on the coronal MRI in order to standardize measurements across varied heights. These were labeled as Zone 1 being the most distal zone, Zone 2 being the middle zone, and Zone 3 being the most proximal zone. Zones 1 and 2 were further subdivided into 3 sections to create 6 total zones of study (Fig. 1), labeled A, B, and C from distal to proximal within their respective zones. Zone 3 was excluded as this was deemed to be too proximal for feasible pin placement during surgery.

For each zone of study on a coronal MRI of the femur, the correlating axial image was produced using scout mode technique (Fig. 2a). Whiteside's line and a line perpendicular to it were drawn on each of the corresponding axial images to divide the femur into 4 quadrants in this plane. Consistent with manufacturer technique, femoral pin placement was replicated by drawing a line angled 45° from the anterior to posterior reference in the anteromedial quadrant (Fig. 2b). This line was extended beyond bicortical limits in order to most accurately depict the risk that femoral pin placement poses. The distances to identified neurovascular structures were then measured and recorded (Fig. 3).

The distances from the projected femoral pin paths to the surrounding neurovascular structures were measured using Philips IntelliSpaceRadiology 4.7 and recorded on Microsoft Excel (Microsoft Excel for Mac 2022; version 16.66.1). This software was additionally used to compute mean values and standard deviations for men, women, and combined for each of the 6 zones. In order to compare men and women, a paired 2-tailed T-test function was performed on Excel. A statistically significant result was determined by setting the *P*-value at 0.05.

Study exemption was approved by the institutional review board.

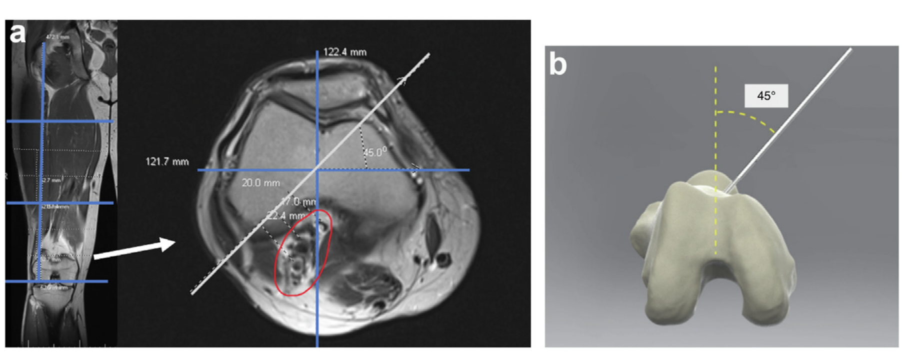

Figure 2. Coronal MRI of right femur with corresponding scout mode axial MRI with neurovascular structures measured from projected femoral pin at 45° (a) and correlating intraoperative image of femoral array in insertion (b). MRI, magnetic resonance imaging.

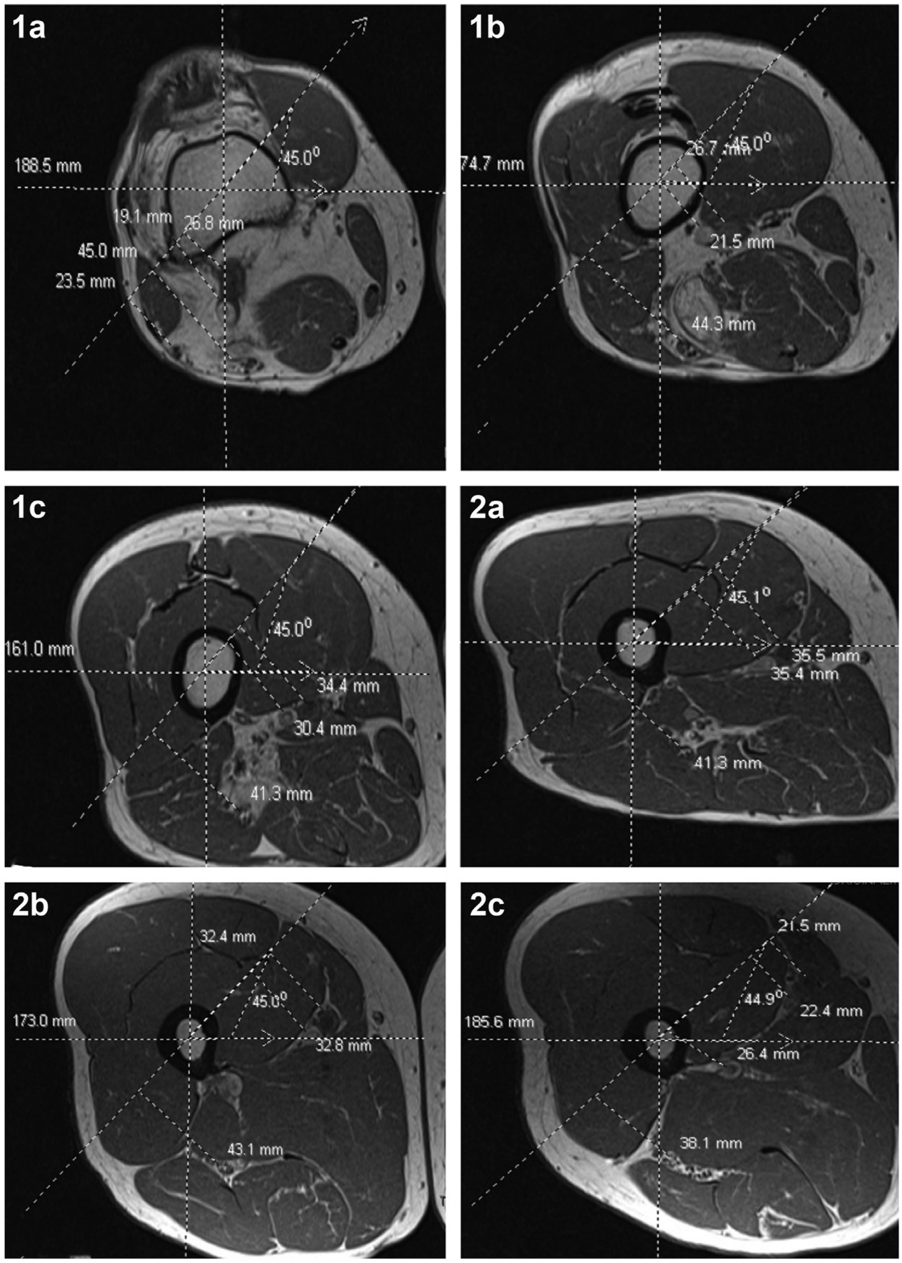

Figure 3. Representative axial MRI of femur at the various zones of study with nearby neurovascular structures identified and distance measured. MRI, magnetic resonance imaging.

Results

Of the 10 MRIs reviewed (5 men, 5 women), the mean age was 72.2 (men: 72.2, women: 72.2, $P > .05$). The laterality consisted of 6 right femurs and 4 left femurs. The popliteal artery and vein, as well as tibial nerve and common peroneal nerve, were within proximity in Zone 1A. Proximally to the bifurcation, in Zones 1C-2C, the femoral artery as well as sciatic nerve were in proximity to the proposed femoral pin path. Most proximally, at Zone 2C, the profunda femoris becomes an additionally present vascular structure.

Table 1
Distance to neurovascular structure of a femoral array pin according to zones along the femur.

Zone	Distance to neurovascular structure ± standard deviation (mm)							
	Femoral artery	Profunda femoris	Femoral vein	Popliteal artery	Popliteal vein	Sciatic nerve	Tibial nerve	Common peroneal nerve
1A	-	-	-	22 (±4.4)	22 (±5.3)	-	31 (±9.8)	21 (±9.2)
1B	29 (±5.6)	-	-	-	22 (±4.1)	-	-	31 (±10)
1C	38 (±6.7)	-	-	-	30 (±6.2)	35 (±10)	-	-
2A	40 (±8.0)	-	38 (±8.8)	-	-	35 (±11)	-	-
2B	30 (±9.0)	-	29 (±6.8)	-	-	36 (±8.1)	-	-
2C	14 (±7.4)	23 (±7.3)	14 (±7.6)	-	-	32 (±8.3)	-	-

Table 2
Distance to neurovascular structure of a femoral array pin according to zones along femur, grouped by sex.

Zone	Neurovascular structure in closest proximity	Distance to neurovascular structure ± standard deviation (mm)		*P* value
		Men	Women	
1A	Common peroneal nerve	26 (±7.6)	14 (±7.0)	.03[a]
1B	Popliteal vein	25 (±4.2)	20 (±2.6)	.07
1C	Popliteal vein	35 (±3.2)	26 (±5.1)	.01[a]
2A	Sciatic nerve	42 (±8.7)	28 (±7.4)	.03[a]
2B	Femoral vein	34 (±3.2)	25 (±7.1)	.04[a]
2C	Femoral artery	16 (±9.4)	11 (±3.7)	.24

[a] $P < .05$ denotes statistical significance.

These results, with specific measurements, are summarized in Table 1.

The closest neurovascular structure to the proposed femoral pin path differed according to zone along the femur. In 4 out of 6 zones, women had a statistically significant shorter distance to neurovascular structures than men (Table 2).

Discussion

Currently, there is no established standard for the placement of femoral pins in RATKA with regards to the safety of neurovascular structures. Neurovascular injury in TKA has been studied extensively in both primary and revision settings [14–16]. When performing RATKA, the femoral array pins must be placed more proximally, so the concerns of pin placement exist throughout the length of the femur. The most important finding of this study is that femoral pin placement from the anteromedial to posterolateral quadrant at a 45° angle poses significant risk to the neurovascular structures within 1-2 cm throughout the proximal and distal femur. Specifically, Zone 2C demonstrated femoral pin trajectory an average of 14 mm from the femoral artery and vein, and Zone 1 A demonstrated the popliteal artery and vein were on average 22 mm from the femoral pin, while the common peroneal nerve was an average of 21 mm. This risk was additionally increased in women. Furthermore, placing pins at the most distal zone (1A) poses a high risk of injury to the genicular arteries. In a cadaveric study, Barner *et al.* [17] mapped out the genicular arteries of 46 knees and found that the superior medial geniculate and superior lateral geniculate were 57.3 mm ± 8.1 mm and 55.2 ± 6.2 mm from the joint line, respectively. In the 10 studied MRIs, the most distal zone is consistently just below this level (Fig. 4). Given these findings, we recommend avoiding pin placement this distally in the femur.

While study on pin site placement has been sparse, there is previous literature that does report on the potential dangers to neurovascular structures. In their cadaveric study, Marchant *et al.* [13] described pin placement in the distal most quadrant of the femur with a trajectory of 30 degrees as passing within 5 mm of the sciatic and peroneal nerve in 100% of cases. In comparison, our measurements performed at a 45° angle increased the average distances to 21 mm. This highlights the posterior location of neurovascular structures and that surgeons should be cautious to not err with an acute angle trajectory less than 45° from the anterior to posterior plane. Our finding that women had a greater risk of proximity to neurovascular structures is also consistent with the established literature [18].

Our study did have several limitations. First, the limited sample size of 10 (5 men and 5 women) MRIs potentially reduces the accuracy and generalizability for the results of the mean distance values from neuromuscular structures. The limitation arose largely due to the narrow age group of focus. Future studies can expand on the number of samples analyzed. Next, significant differences in femur size and morphology exist. To accurately determine pin placement throughout the femur, we proposed division into zones instead of distance from the joint line, as is frequently described in manufacturer technique guides. This accounts for differences in heights and lengths of femurs, although this would require intraoperative measurement and assessment by the surgeon for each individual patient. As age would be unlikely to create anatomic variation in the patient population that would be undergoing TKA, we chose the most common age group to receive TKA and compared findings between men and women [19]. Although variations in anatomy have been described with the knees in varying degrees of flexion [20], our study was performed with all samples supine in the MRI scanner, which may not replicate intraoperative

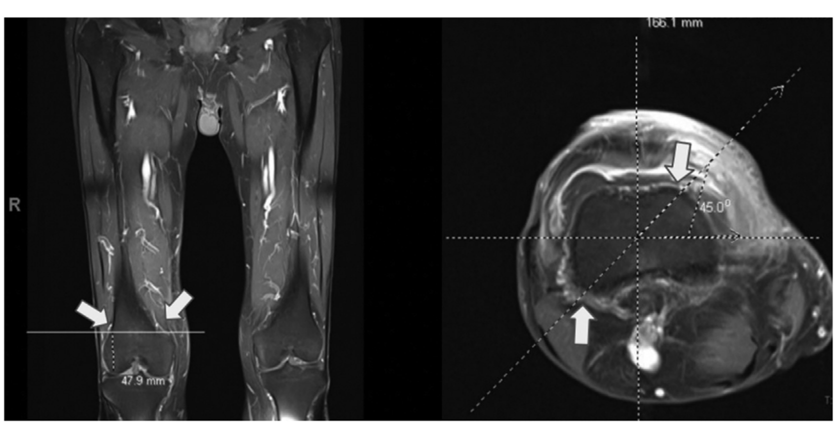

Figure 4. Coronal MRI of right femur with corresponding scout mode axial MRI at most distal zone (1A) with geniculate arteries labeled (white arrows) and projected femoral pin at 45°. MRI, magnetic resonance imaging.

conditions. Image analysis showed that correcting for femoral version did not significantly impact the projected femoral pin insertion trajectory and thus no impact on distance from pin to neurovascular structures; however, considerations should be taken for pin placement with altered limb alignment.

Conclusions

Our proposed classification system for safe zones and trajectory of femoral pin placement in RATKA demonstrates that proximally, the profunda femoris and femoral artery/vein are at risk of injury, while distally, the genicular arteries, the common peroneal nerve, and popliteal artery/vein are at risk. Caution should be exercised particularly if femoral pins are inserted with an angle less than 45°, especially in women.

Conflicts of interest

Victor Hugo Hernandez is a board member of AALOS, MOS, and AAHKS International Committee and received Research support from OMEGA and OREF. Jaime Carvajal Alba is a part of speakers bureau/paid presentations and a paid consultant for Smith and Nephew Consultant. All other authors declare no potential conflicts of interest.

For full disclosure statements refer to https://doi.org/10.1016/j.artd.2023.101186.

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