

Distances between popliteal vessels to the femur and anthropometric impacts on distal femoral fracture surgery outcome: a retrospective study

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Research article

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Abstract

Background:

The proximity of the popliteal vessels in the distal femur may increase the risk of iatrogenic vascular injury during cerclage wiring. In this study, the closest location and distance of the popliteal vessels to the femur was examined using magnetic resonance imaging (MRI). The associations between anthropometric factors and the distance that would guide the placement of wires safely during surgery were also identified.

Methods:

We reviewed knee MRIs of 206 adults and recorded 1) the relation as well as the shortest horizontal distance (d-H) from the femoral cortex to the popliteal vessels in axial images and 2) the vertical distance (d-V) from the adductor tubercle to the axial level of d-H in coronal images. The effects of anthropometric factors (i.e., gender, age, body height, body weight, body mass index, thigh circumference, femoral length, and femoral width) on these distances were analysed.

Results:

The closest locations of popliteal vessels were at the posteromedial aspect of the femur. The d-H and d-V were 7.38 ± 3.22 mm, and 57.01 ± 11.14 mm, respectively, and were both shorter in women than in men ($P < 0.001$). Multivariate analysis identified thigh circumference and femoral length as the most influential factors for the d-H and d-V, respectively ($P < 0.001$). Linear regression demonstrated a strong positive linear correlation between the thigh circumference and the d-H and between the femoral length and the d-V (Pearson's $r = 0.891$ and 0.806 , respectively [$P < 0.001$]).

Conclusions:

The closest location and distance of the popliteal vessels to the femur provide useful information for wire placement during distal femoral fracture surgery while minimising the risk of vascular injury. Given that patients with smaller thigh circumference and shorter femoral length are more likely to have smaller d-H and shorter d-V, respectively, cautious measures should be taken in such cases.

Trial registration:

retrospectively registered

Background:

Cerclage wiring is one of the most common and effective fixation methods to distal femur fractures [1–3]. Unfortunately, irrespective of open or percutaneous technique, there are as many as 7% of vascular

complications associated with inadequate use of cerclage wires [1, 4]. Indeed, occlusion of major vessels by cerclage wire could result in severe issues, such as below knee amputation [5].

Managing vascular injuries associated with distal femoral fracture surgery requires awareness of the anatomy of the popliteal vessel and the distal femur and adequate wire placement. The superficial femoral artery (SFA) crosses from anterior-superior to posterior-inferior in the distal third of the femur, then exits from the adductor hiatus (AH) to become the popliteal artery (PA), which comes closely to the cortex [6].

The proximity of the popliteal vessels to the distal femur may increase iatrogenic injury during cerclage wiring of the distal femoral fracture. Few studies focused on the vascular structure or AH in the distal third of the femur. In two cadaveric studies, it was reported the area up to 8 cm proximal to the adductor tubercle (AT) to be safe from vascular damages during surgery and localisation of the apex of the AH could be determined by a bony landmark [7]. However, the spatial resolution of the popliteal vessels in relation to the femur have not yet been examined and the effects of the anthropometric factors on such measures have not been elucidated.

This study aimed to determine (1) the closest location and distance of the popliteal vessels to the femur in adults on magnetic resonance imaging (MRI) and (2) the significance of associations between anthropometric factors (i.e., gender, age, body height, body weight, body mass index [BMI], thigh circumference, femoral length, and femoral width) and the distance that would guide the placement of wires to minimize the risk of vascular injuries during distal femur fracture surgery.

Methods

Patients

After obtaining institutional review board approval (CMUH109-REC3-106), we conducted a retrospective review of 206 consecutive knee MRI studies (ligament and meniscus lesions [N = 117], osteoarthritis [N = 47], spontaneous osteonecrosis of the knee [N = 23], and osteochondritis dissecans [N = 19]) performed on 206 patients between 20 and 80 years of age during a 5-year interval (January 2015 to December 2019). All studies had a written report submitted by a musculoskeletal radiologist (HYC) at our institution. All cases were on unilateral knees. The age of each patient at the time of the study was recorded. An electronic query and manual review of the medical records were completed to obtain patient anthropometric factors, including gender, body height, body weight, and thigh circumference, which was measured horizontally just distal to the *gluteal fold* [8]. BMI was calculated as weight in kilograms (kg) divided by height in meters (m) squared (kg/m^2). The femoral length and width, defined as the distance from the tip of the greater trochanter (GT) to the AT, and the widest portion of the distal femur, respectively [9], were reviewed on lower limb scanograms.

Knee MRI

Patients were scanned with a 1.5 Tesla Signa MRI scanner (General Electric Medical Systems, Milwaukee, WI) in the supine position, with both lower extremities straight and knees extended. T1-weighted images in the axial, sagittal, and coronal planes with slice thickness of 2 mm were selected on each knee MRI for analysis. The distances (in millimetres, mm) were measured using a digital calliper tool within INFINITT's Picture Archiving and Communications System (PACS).

In the axial images, the shortest horizontal distance (d-H) from the femoral cortex to the popliteal vessels was measured after tracing nearby cuts of AH (Fig. 1a). In the coronal images, the vertical distance (d-V) from the axial cut of AT to the "d-H" axial level was measured (Fig. 1b). The posterior condylar axis (PCA), a line connecting the most posterior border of the medial and lateral condyle in the axial view, was used as a reference to set the sagittal plane of the femur (Fig. 1c). The posterior half of the femur was defined by a line paralleling the PCA and crossing the centre of femoral canal, as described by Kim et al. [10]. At each "d-H" axial level, the posterior half of the femur was divided into eight sections that labelled "A to H" from posteromedial to posterolateral, and the position of the popliteal vessels was noted (Fig. 1d). One musculoskeletal radiologist (HYC) and two orthopaedic surgeons (HWC, TLL) recorded all measurements independently, and the mean between three physicians was used for data analysis.

Statistical Analysis

Statistical analyses were performed using SPSS for Windows, version 21.0 (SPSS Inc., Chicago, IL, USA). The reliability of each measurement was examined by the intra-class correlation coefficient (ICC). Continuous data are presented in the form of mean \pm standard deviation. Groups were compared using a *t*-test for independent samples. The effects of gender, age, body height, body weight, BMI, thigh circumference, femoral length, and femoral width on each measurement were evaluated using multivariate linear regression analysis. The coefficient of determination, R^2 , was used to check the goodness of fit of the statistical models and as a measure of how much of the original uncertainty in the data was explained by the multivariate analysis. R^2 varied between 0 and 1, with 0 indicating no benefit gained by applying multivariate analysis, and 1 indicating benefit. The correlation between the most influential anatomical factor and distance measurements was analysed using Pearson's correlation coefficient and significant differences with Games-Howell post-hoc analysis. Statistical significance was set at $P < 0.05$.

Results

The study group included 110 men and 96 women with a mean age of 47.55 years (range 20–80), height of 165.53 centimetre (cm) (range 138–188), body weight of 69.62 kg (range 39–140), BMI of 25.24 (range 16.92–40.17), thigh circumference of 479.33 mm (range 360–649), femoral length of 413.85 mm (range 330.16–479.84), and femoral width of 84.17 mm (range 64.13–100.41).

The knee MRI included 113 right and 93 left sides. The majority position of the popliteal vessels adjacent to femoral cortex was section C (109/206, 52.9%), followed by section B, D, and A (27.2%, 19.4%, and

0.5%, respectively). The ICC of d-H and d-V were 0.915 (range 0.883–0.947) and 0.923 (range 0.897–0.961), respectively. The d-H was 7.38 ± 3.22 mm. The d-V was 57.01 ± 11.14 mm. There was no significant difference in the distances between the groups of different pathologic diagnosis of knees ($P=0.721$).

There was a significant difference between genders in their d-H and d-V as well as body height, body weight, BMI, thigh circumference, femoral length, and femoral width ($P < 0.001$, < 0.001 , 0.008 , 0.002 , < 0.001 , and < 0.001 , respectively; Table 1), Because the gender difference might account for changes in d-H and d-V, multivariate analysis was performed.

Table 1. Gender differences in anthropometric factors, d-H and d-V			
	Men (n = 110)	Women (n = 96)	P value
Age (years)	44.98 ± 15.72	44.84 ± 17.46	0.952
BH (cm)	172.25 ± 6.90	157.74 ± 8.44	< 0.001
BW (kg)	77.47 ± 16.50	60.58 ± 11.71	< 0.001
BMI (kg/m ²)	25.99 ± 4.59	24.33 ± 4.24	0.008
TC (mm)	489.58 ± 55.18	467.57 ± 44.36	0.002
FL (mm)	432.16 ± 25.97	392.86 ± 28.31	< 0.001
FW (mm)	88.61 ± 5.81	78.96 ± 6.25	< 0.001
d-H (mm)	7.92 ± 3.42	6.76 ± 2.86	0.010
d-V (mm)	61.79 ± 9.39	51.54 ± 10.49	< 0.001
Data are presented as mean \pm standard deviation			
BH, body height; BW, body weight; BMI, body mass index; TC, thigh circumference; FL, femoral length; FW, femoral width; d-H, the closest horizontal distance between popliteal vessels to the femoral cortex; d-V, the vertical distance between AT to the axial level of d-H			

The results are shown in Table 2. The total effect of these anthropometric factors, R^2 , on the d-H and d-V were 0.788, and 0.667, respectively. The d-H correlated with thigh circumference ($P < 0.001$) but not with gender, body height, body weight, BMI, thigh circumference, femoral length, or femoral width. The d-V correlated with femoral length ($P < 0.001$) but not with gender, body height, body weight, BMI, thigh circumference, or femoral width.

Table 2. Multivariate analyses on distances between popliteal vessels to the femur				
Distances	B estimate	SE	P value	R2
d-H				0.788
Intercept	-22.378	8.662		
Gender	-0.015	0.295	0.960	
Age (years)	0.000	0.007	0.986	
BH (cm)	0.024	0.054	0.655	
BW (kg)	-0.025	0.058	0.673	
BMI (kg/m ²)	0.061	0.163	0.711	
TC (mm)	0.056	0.003	< 0.001	
FL (mm)	-0.003	0.006	0.676	
FW (mm)	0.027	0.018	0.126	
d-V				0.667
Intercept	-90.768	37.717		
Gender	-2.513	1.286	0.052	
Age (years)	0.039	0.029	0.181	
BH (cm)	0.395	0.234	0.094	
BW (kg)	-0.094	0.253	0.712	
BMI (kg/m ²)	0.557	0.712	0.435	
TC (mm)	-0.026	0.013	0.068	
FL (mm)	0.210	0.028	< 0.001	
FW (mm)	0.147	0.077	0.057	
SE, standard error; BH, body height; BW, body weight; BMI, body mass index; TC, thigh circumference; FL, femoral length; FW, femoral width; d-H, the closest horizontal distance between popliteal vessels to the femoral cortex; d-V, the vertical distance between AT to the axial level of d-H				

The linear regression equations predicting d-H and d-V were as below formulas:

$$d-H \text{ (mm)} = 0.056 * \text{thigh circumference (mm)} - 19.282 \text{ (Fig. 2a)}$$

$$d-V \text{ (mm)} = 0.269 * \text{femoral length (mm)} - 54.184 \text{ (Fig. 2b)}$$

These formulas predicted that patients with smaller thigh circumference (especially smaller than 399 mm) have smaller d-H (Table 3), and those with shorter femoral length (especially smaller than 369 mm) have shorter d-V (Table 4).

Table 3

The closest horizontal distance between popliteal vessels to femoral cortex based on thigh circumference

Thigh circumference (mm)						
	≤ 399 (n = 8)	400–449 (n = 55)	450–499 (n = 79)	500–549 (n = 48)	≥ 550 (n = 16)	P value
d-H (mm)	2.93 ± 1.01	4.37 ± 1.31	6.95 ± 1.66	10.35 ± 1.55	13.10 ± 2.24	< 0.001
Data are presented as mean \pm standard deviation						

Table 4

The vertical distance between adductor tubercle to level of d-H based on femoral length

Femoral length (mm)						
	≤ 369 (n = 26)	370–399 (n = 37)	400–429 (n = 70)	430–459 (n = 55)	≥ 460 (n = 18)	P value
d-V (mm)	38.55 ± 6.40	49.76 ± 5.76	58.97 ± 57.51	64.65 ± 8.15	67.62 ± 6.63	< 0.001
Data are presented as mean \pm standard deviation						

Discussion:

The proximity of the vascular structures traversing the AH in the distal femur may increase the risk of iatrogenic popliteal vascular injury during cerclage wiring. In the current study, reference values for safe distances from injury and the closest location of popliteal vessels to the femur were established using MRI in adult knees. The closest locations of popliteal vessels were at posteromedial aspect of the femur. The d-H and d-V were 7.38 ± 3.22 mm, and 57.01 ± 11.14 mm, respectively. We also assessed the effect of anthropometric factors on these distances and found thigh circumference and femoral length to be the most important indicators for the d-H and d-V, respectively.

Distal femur fractures account for about 6% of all femoral fractures [11–13], and vascular injuries around 2% [14]. Injury to the SFA, deep femoral artery (DFA), or PA have been described as a result of broken sharp fragments or iatrogenic injuries such as external fixation pins, plunging drill bits, medial plating, or cerclage wiring. These damages could give rise to immediate bleeding, late presented pseudoaneurysm, limb ischemia, or below knee amputation [1, 5, 15–17].

Apivatthakakul et al. evaluated computed tomography angiography (CTA) of 80 patients, which divided the whole femur into eight equal segments (7 levels) from the tip of the GT to the lateral tibiofemoral joint line in the coronal plane and eight equal directions from anterior to posterior of the medial femur in the axial plane. They found that when the SFA was at levels 6 and 7, it was located between sectors F and H (posteromedial and posterior to the femur) and at a distance of about 13.63 ± 3.59 mm and 10.08 ± 3.09 mm, respectively [18]. Their result was similar to the current study, which revealed closest point of popliteal vessels to situate posteromedial and posterior to the femur. During cerclage wiring, either from anterolateral or posterolateral direction, surgeons should be cautious of posteromedial and posterior aspects of the femur. The present study demonstrated the precariousness of popliteal vessels and that any distance shorter than the closest one shown here between the vessels and femur cortex could prove more detrimental than previously thought; we would also strongly suggest subperiosteal over blunt dissection during wiring, where the wire passer tips are as close to the bony cortex as possible or at low-risk position from the popliteal vessels, to avoid vascular injury.

To our best knowledge, this was the first study of d-H in the literature, which demonstrated smaller d-H in small thigh circumference patients. The explanation for this association is still uncertain. While the influence of obesity on the anatomical relationship between the PA and tibial nerve in the popliteal fossa had been reported, no direct evidence between the popliteal vessels and the femur cortex were described [19]. Even though we had hypothesised the d-H was relevant to the thickness of the fatty tissue around the popliteal fossa, no correlation between the measurement and body weight or BMI was noted. Therefore, body fat percentage and regional distribution should be included for evaluation in future studies.

There is a transition zone in the hiatal area, from the adductor canal to the popliteal fossa. In comparison with the more flexible fatty tissue of the popliteal fossa, the region of AH is more rigid and fixes the junction of SFA and PA close to the femur cortex [7]. Kwon et al. reported the level of AH to be over 59.8 mm proximal to the superior border of the patella [20]. Cadaveric studies with 24 and 28 thighs described the level of AH to be above 10 cm (range 8.0-13.5 cm) and 7.4 cm (range 5.6–9.2 cm) from the AT, respectively [21, 22]. Kanawati et al. assessed 41 limbs using CTA to describe the relationship between the SFA and the whole femoral shaft and warned of the “danger zone” from 239.6 mm to 172.5 mm proximal to the AT [9]. In the current study, the d-V (57.01 ± 11.14 mm) was shorter than the distance between AT and AH described in the literature [21, 22]. This suggests that the closest level of vascular bundle occurs slightly distal to the AH, at the point where the PA crosses posteriorly to the distal femur.

Kanawati et al. proposed doubled width of the femoral condyles as an estimated safe distance proximal to the AT for intervention [9]. They also mentioned the danger zone where SFA crossed inferiorly by halving the distance between GT and AT. Both predictors could be measured on a true anteroposterior (AP) radiograph preoperatively or intraoperatively. In the current study, surgeon could estimate d-H and d-V preoperatively based on the thigh circumference and the femoral length, respectively, without CTA or MRI. The thigh circumference could easily be computed directly below the gluteal fold [8]. The femoral

length could be calculated from length between GT and AT on the AP view of a whole femur radiograph. Although there is a little difference between bilateral thigh, the thigh circumference and the femoral length could be used clinically by measuring the normal contralateral instead of the fractured limb.

Limitations

This study has several limitations. First, our distances were measured on MRIs and not intraoperatively. Given that the MRIs were taken with the patient in a supine position, while some distal femoral fracture surgeries were performed with the patient in a lateral decubitus position, certain anatomical relationships may differ. Second, the direction of the femoral artery in the current study was dependent on the neutral position of the intact femur. Although the position was similar to most of the clinical conditions that used lateral approach in the distal femur, there were several factors including medial approach, extremity location, traction, soft tissue retractor, and the displacement of bony fragment that could influence the distance between the popliteal vessels and the femoral cortex. Third, instead of measuring the distances on 2D MRI scans, it would be more reliable to make 3D reconstructions using software such as Mimics® (Materialise, Leuven, Belgium) of the soft tissue of interest, i.e. the vessels, and relate those distances to the 3D bony landmarks. Furthermore, given that all subjects presented here were of unrelated Han Chinese ethnicity, it would be interesting to conduct this work in other populations.

Strengths

Several methods of evaluating the location of femur artery have been utilised including cadaveric dissection [7, 22, 23], ultrasonography, angiography [14, 24], CTA [6, 9, 10, 17, 18, 25], and MRI [26–28]. We believed MRI provided more valuable information about relationships between soft tissues, including neurovascular bundle, muscles, and fatty tissues. In addition, the innovation of non-contrast-enhanced MR technique improved the resolution of soft tissue anatomy without the risk of contrast-induced complication as seen in angiography or CTA [26, 29]. Moreover, the sample size in our study was larger and the analysed MRIs were used to assess structurally pathologic knees, which was reflective of the anatomical reality in patients who were actually undergoing surgery. All distances were independently measured by three physicians. Therefore, the results provided could be viewed as reliable reference data in future work.

Conclusions:

By measuring a large number of adult knee MRIs, this study found the closest location and distance of the popliteal vessels to the femur to provide useful information for wire placement during distal femoral fracture surgery while minimising risk of vascular injury. Surgeons should strive to perform subperiosteal dissection and pass the wire passer tips as close to the bony cortex as possible during wiring to avoid vascular injury based on the patient's thigh circumference. The vertical positions of the cerclage wire should be checked intraoperatively based on the AT and the femur length to estimate the low-risk position from the popliteal vessels. Given that patients with smaller thigh circumference and shorter femoral

length are more likely to have smaller d-H and shorter d-V, respectively, cautious measure should be taken in such cases.

Abbreviations

SFA: superficial femoral artery; AH: adductor hiatus; PA: popliteal artery; AT: adductor tubercle; MRI: magnetic resonance imaging; BMI: Body mass index; Kg: kilogram; m: meters; GT: greater trochanter; mm: millimetre; PACS: Picture Archiving and Communications System; d-H: the shortest horizontal distance from the femoral cortex to the popliteal vessels in axial images; d-V: the vertical distance from the AT to the axial level of “d-H” in coronal images; PCA: posterior condylar axis; ICC: intra-class correlation coefficient; R²: coefficient of determination; cm: centimetre; BH: body height; BW: body weight; TC: thigh circumference; FL: femoral length; FW: femoral width; DFA: deep femoral artery; CTA: *computed tomography angiography*, AP: anteroposterior.

Declarations

Ethics approval and consent to participate

CMUH109-REC3-106

Consent for publication

Written informed consent was obtained from the patient for the publication of this report and any accompanying images.

Availability of data and materials

All data generated and/or analysed during this study are included in this published article.

Competing interests

The authors declare that they have no competing interests

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Authors' contributions

TLL and CJH contributed to the conception and design of the study. HWC and CYL contributed to drafting the article. HYC and YWC collected the patient data. HTC and IHL performed statistical analysis. All authors read and approved the final manuscript.

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Authors' information

As in the title page

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Figures



Figure 1

Magnetic resonance images demonstrating the views used for measuring distances from the popliteal vessels to the femur: a. the closest distance (d-H) between the popliteal vessels to the femoral cortex; b. the distance (d-V) between the adductor tubercle and the axial level of “d-H”; c. the posterior condyles axis in the femur was used as a reference line (0°); d. posterior half of the femur divided into eight sections labelled from A to H and from posteromedially to posterolaterally.

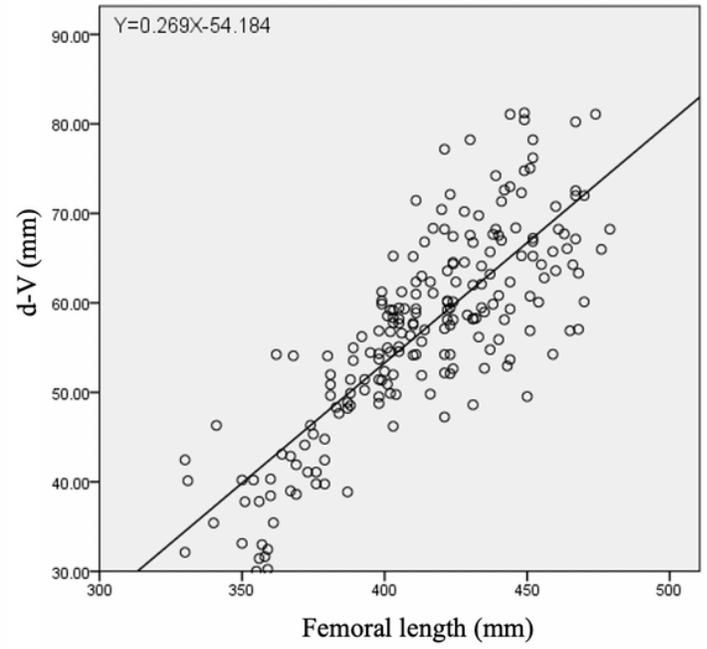
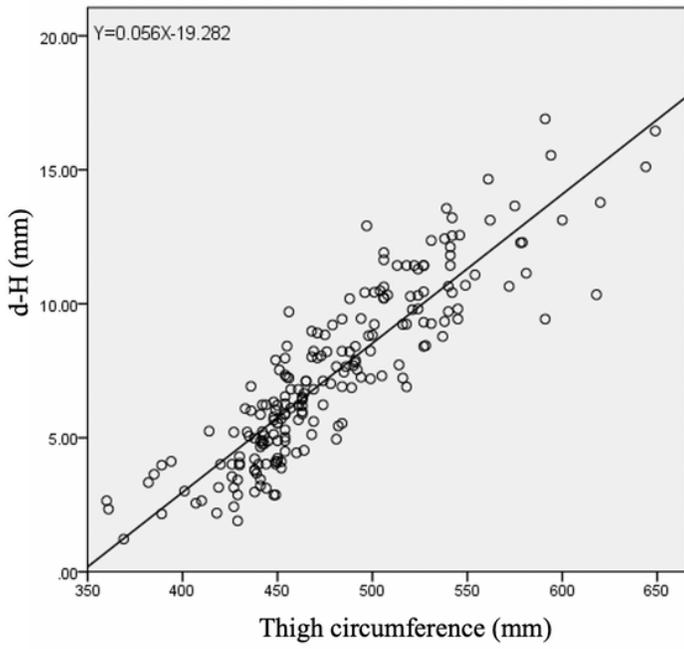


Figure 2

The simple linear regression model describing the relationship between: a. thigh circumference and d-H; b, femur length and d-V.