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ORIGINAL ARTICLE

The effect of skin entry site, needle angulation and soft tissue compression on simulated antegrade and retrograde femoral arterial punctures: an anatomical study using Cartesian co-ordinates derived from CT angiography

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Abstract
Purpose Safe femoral arterial access is an important procedural step in many interventional procedures and variations of the anatomy of the region are well known. The aim of this study was to redefine the anatomy relevant to the femoral arterial puncture and simulate the results of different puncture techniques.
Methods A total of 100 consecutive CT angiograms were used and regions of interest were labelled giving Cartesian co-ordinates which allowed determination of arterial puncture site relative to skin puncture site, the bifurcation and inguinal ligament (ING).
Results The ING was lower than defined by bony landmarks by 16.6 mm. The femoral bifurcation was above the inferior aspect of the femoral head in 51% and entirely medial to the femoral head in 1%. Simulated antegrade and retrograde punctures with dogmatic technique, using a 45-degree angle would result in a significant rate of high and low arterial punctures. Simulated 50% soft tissue compression also resulted in decreased rate of high retrograde punctures but an increased rate of low antegrade punctures.
Conclusions Use of dogmatic access techniques is predicted to result in an unacceptably high rate of dangerous high and low punctures. Puncture angle and geometry can be severely affected by patient obesity. The combination of fluoroscopy to identify entry point, ultrasound-guidance to identify the femoral bifurcation and soft tissue compression to improve puncture geometry are critical for safe femoral arterial access.

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Introduction

Safe femoral arterial access is an important procedural step in many interventional procedures performed by cardiologists, interventional radiologists, interventional neuroradiologists and vascular surgeons. Femoral arterial access should be obtained into the common femoral artery (CFA) over the middle third of the femoral head [13]. High punctures above the inguinal ligament (ING) are at risk of causing retroperitoneal haemorrhage [8]. Low punctures below the bifurcation have a higher risk of pseudoaneurysm formation [5].

The anatomy of this region has been defined by several studies which have made measurements in cadavers, or been performed through the review of angiograms. This anatomy is well summarized in a recent article [8]. Key features are that (1) the ING is 1–2 cm lower than predicted by using traditional bony landmarks, (2) the femoral bifurcation can be above the inferior border of the femoral head, (3) the femoral artery tends to overly the medial third of the femoral head, but can be completely medial.

Historically, many different techniques have been used to gain percutaneous access to the femoral artery and some of these have fallen out of favour due to risk of complications. Traditional techniques using landmarks such as the inguinal skin crease (CR) are considered dangerous as the CFA bifurcation is actually above the CR in 72% [6]. Other landmark techniques include the use of fluoroscopic screening to identify the inferior border of the femoral head as the skin entry site.

However, the above anatomical variations can result in higher risk of complications if dogmatic techniques are used. If landmarks are used, a high femoral bifurcation or low ING may lead to complications. If fluoroscopy is used to make sure that the landmark involves the femoral head, arterial puncture may be unsuccessful, as the artery may lie medial to the femoral head. These anatomical variations may be why some operators favour punctures performed under direct ultrasound visualization [3].

The aims of this study were to define the anatomy relevant to the femoral arterial puncture, in terms of the location of the ING, femoral head and femoral bifurcation relative to the CFA at the midpoint of the femoral head and to determine ideal antegrade and retrograde punctures sites and angulations and to simulate the result of different puncture techniques at different skin entry sites.

Methods

Ethical approval for this study is not required by our department. The PACS database was used to harvest consecutive CT angiograms. The CT scans were performed on Definition AS+ or Flash scanners (Siemens, Erlangen, Germany) and reconstructed to 1.5 mm slice thickness. Scans with significant arterial pathology, previous groin surgery or those with hip prostheses were excluded (due to the presence of artefact from the prosthesis). The 1.5 mm slices from the iliac crests to the lesser trochanters were harvested and sent as DICOM files to a remote workstation node (Osirix 32-bit, v. 3.1). The median age was 74 (mean 72.3, range 39–89).

The axial images were then reconstructed in the coronal plane and point regions of interest (ROIs) were used to label the following points—pubic tubercle (PT), anterior superior iliac spine (ASIS), ING as it crossed the CFA, skin crease (CR) in line with the CFA, the superior (SUP), inferior (INF) and medial (MED) aspect of the femoral head, the CFA at the midpoint of the femoral head (CFA), and the origin of the profunda femoris artery (PFA) (see Fig. 1). Each point was labelled using the 'point region of interest' tool. After these points were labelled, the data were exported as a comma-separated value file (.csv file). The axial images were then reconstructed in the sagittal plane, and skin entry sites at the superior aspect (ES) and inferior aspect (EI) of the femoral head were also recorded (i.e. where the skin entry site would be if the needle were held vertically and aligned toward the superior margin of the femoral head) (Fig. 2). These were also exported as a .csv file. The .csv files contained the true Cartesian co-ordinates for all the above datapoints, and were opened with Excel (Microsoft Corporation, Redwood, CA, USA).

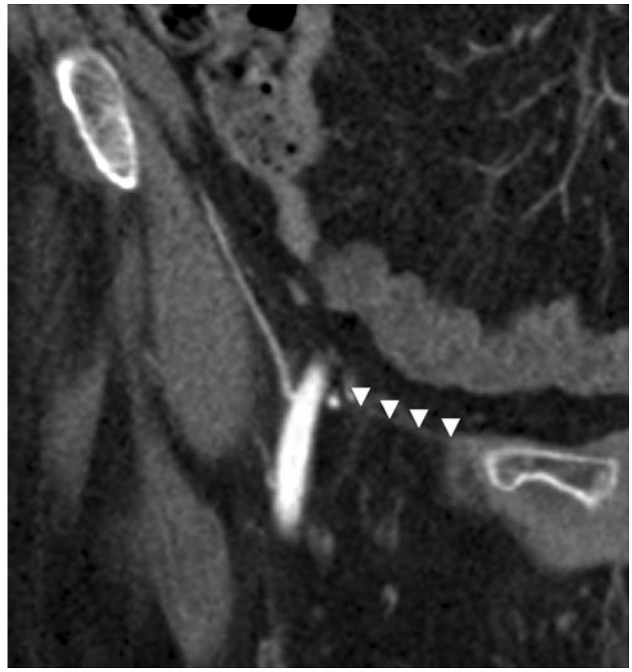

Fig. 1 Coronal view of the inguinal ligament as it crosses the common femoral artery (ING)

The datapoints from all 100 CT scans were accordingly transferred into a master Excel file.

The *x*, *y* and *z* co-ordinates were then known for each datapoint in 100 CT scans. The *z* co-ordinates of PT, ASIS and ING were used to determine the true position of the ING as it crossed the CFA, i.e. Iz – 1/2(Az – Pz).

The *z* co-ordinates of the SFA and PFA were averaged and compared to the *z* co-ordinate of INF to determine the relative site of the femoral bifurcation to the inferior border of the femoral head, i.e. INFz − 1/2(SFAz + PFAz).

The *x* co-ordinates of the MED and CFA were compared to determine the position of the artery relative to the medial border of the femoral head. The *z* co-ordinates of SUP and INF were used to calculate the width of the femoral head, using the assumption that the femoral head as a circle, i.e. MEDx − CFAx.

Trigonometry was used to determine the angle of puncture. For each puncture, the opposite and adjacent values could be calculated using the *z* and *y* co-ordinates of the CFA and ES/EI/CR. The angles of retrograde and antegrade punctures were then calculated using the following formula: $A = \tan - 1$ (O/A) (see Fig. 3).

Finally, using the known *z* co-ordinate of the entry point and the CFA, punctures performed at 45 degrees could be tested. The absolute position of the entry site in the *z* plane could be calculated, and this could be measured against the *z* co-ordinate of the ING and bifurcation to determine whether the puncture was high or low. For example, given a puncture angle of 45 degrees, EIy − CFAy = vertical

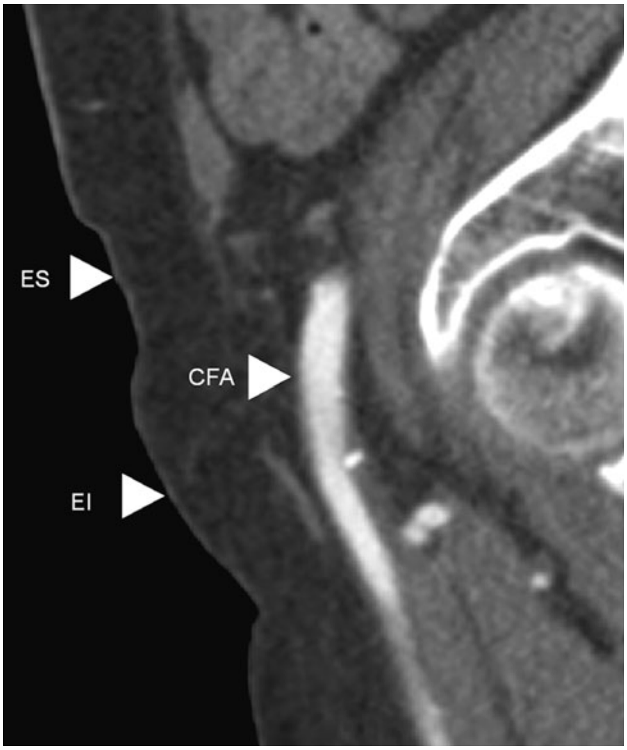

Fig. 2 Sagittal image with skin entry sites at the level of the superior (ES) and inferior borders (EI) of the femoral head and the puncture target—the common femoral artery at the midpoint of the femoral head (CFA)

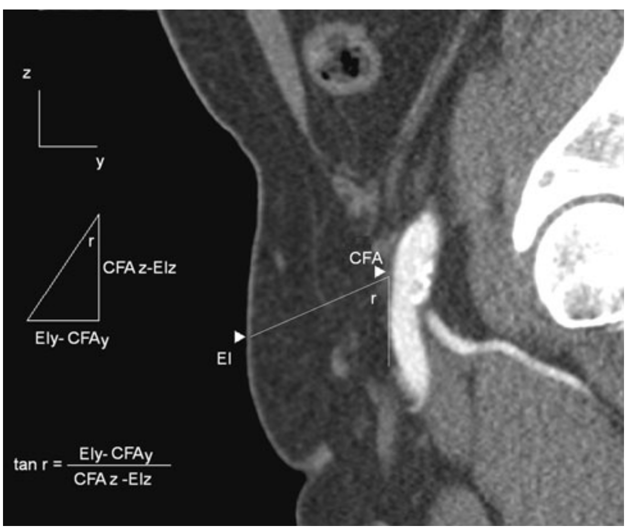

Fig. 3 Calculation of the puncture angle. Similarly, the location of simulated punctures can be determined using an angle of 45 degrees, given that the y and z co-ordinates of the entry point and artery, and the z co-ordinate of the inguinal ligament and femoral bifurcation are known

gain of the puncture. Therefore, EIz + (EIy − CFAy) can be compared to INGz and 1/2(SFAz + PFAz) . Punctures were repeated with a '50% compression factor' of the soft tissue corresponding to EIz + 1/2(EIy − CFAy) in the case of the puncture starting at the level of the inferior aspect of the femoral head. The 50% compression factor was chosen as an arbitrary figure, based on experience that compression in overweight patients can help significantly, but the access can remain challenging.

Results

The ING was lower than as defined by bony landmarks, and on average was 16.6 mm lower than expected at the midinguinal point (range 0–31 mm, 95% CI 4.3–28.9 mm).

The femoral bifurcation was above the inferior aspect of the femoral head in 51%. This was only 0–1 cm above in 36%, 1–2 cm above in 10%, and more than 2 cm above in 5%. Given the mean femoral head height/width was calculated to be 45.2 mm, up to 5% of bifurcations were around or above the midpoint of the femoral head.

At a level halfway up the femoral head, the CFA overlied the medial half of the femoral head in 30%. It overlied the medial third in 90%. In the other 10%, only in 1% was the CFA entirely medial to the femoral head, in the other 9%, there was some degree of overlap (taking into account the width of the femoral artery).

Mean angle of a retrograde puncture from the inferior femoral head to the CFA at the midpoint of the femoral head was 58.5 degrees. The mean angle of antegrade puncture from the superior aspect of the femoral head to the CFA at the midpoint of the femoral head was 53 degrees.

A 45-degree retrograde puncture from the skin crease would result in 32 low punctures, 60 acceptable punctures, and 8 high punctures. A 45-degree retrograde puncture from the level of the inferior femoral head would result in 6 low punctures, 48 acceptable punctures and 46 high punctures. Given a soft tissue compression factor of 50%, this puncture would then result in 11 low, 79 acceptable and 10 high punctures.

A 45-degree antegrade puncture from the level of the superior aspect of the femoral head would result in 3 low, 83 acceptable and 14 high punctures. With 50% compression of soft tissues, this puncture would result in 40 low, 59 acceptable and 1 high puncture.

Conclusions

The anatomical results were consistent with previous studies. The ING was 16.6 mm lower than predicted by traditional landmarks. This was similar to the results of a previous study on 10 cadavers, which found this difference to be 15.2 mm [13]. The common femoral bifurcation occurred above the inferior border of the femoral head in

51% and was at or above the level of the middle of the femoral head in 5%. Another study reported a 10% rate of the high bifurcation (at or above the middle of the femoral head) [7]. Other studies based on retrospective review of angiograms found the bifurcation to be an average of 3.4 cm below the middle of the femoral head [2] and below the femoral head in 76% [14]. In terms of its lateral nature, the CFA overlay the medial 1/3 of the femoral head in the majority but in 1% of cases was entirely medial to the femoral head. In a further 10%, this was marginal, again in line with previous studies which found 3% of the lumen being entirely medial [2].

Our method of using point ROIs in the CT is an accurate way of performing measurements. Although selection of the points is operator dependent, 1.5 mm slice reconstructions are likely to reduce sources of error. Similarly, measurements of distances and angles was automated which again may improve accuracy, although human error with data handling cannot be removed. One limitation with the use of the fixed co-ordinate system was that care had to be taken with data that crossed zero when managing the data. Overall, however, use of point ROIs and exporting the co-ordinates as .csv files has proven to be a useful method for measurement studies.

The skin crease has been shown to be a poor landmark in a prospective study of 100 patients undergoing angiography, with no correlation between the skin crease and site of the ING (with an average distance between the two of 6.5 cm) with the femoral bifurcation above the skin crease in 75.6% [11]. In our series, the skin crease punctures were acceptable in only 60% of cases. In 32% of cases, this technique would result in a puncture, which was below the femoral bifurcation. There was also a significant rate of high punctures, presumably due to a skin crease, which was close to the ING in combination with deep soft tissues.

Using the inferior border of the femoral head as the skin entry site also resulted in erratic rates of unacceptable punctures. Using a 45-degree angle without any compression of soft tissues would result in a huge number of high punctures. Similarly, antegrade punctures were also affected by the geometry resulting from a 45-degree angulation with or without soft tissue compression. Given a mean height of the femoral head of 45.2 mm, a 45-degree puncture angle may have unfavourable geometry. If the artery is 45.2 mm deep, and the puncture is started at one end of the femoral head, then the whole of the femoral head will be crossed in either direction and so steeper puncture angles are more favourable, particularly in larger patients. In a dedicated task analysis of arterial puncture which includes up to 100 decision points the authors advocate starting the puncture “further away” to overcome this problem [10].

Multiple techniques are used to gain femoral arterial access. The use of a dogmatic technique must increase the risk of complications due to the well-described variability in anatomy which can occur. The use of the groin skin crease as a landmark has been shown to be dangerous as the CFA bifurcation is actually above the skin crease in 72% [6]. Other landmarks techniques, with or without the use of fluoroscopy appear to have higher rates of complications which cannot be regarded as satisfactory. For example, one technique using bony landmarks without fluoroscopy or ultrasound to puncture a pulseless artery resulted in a successful puncture after an average of 2.8 needle passes, with access of the femoral vein in 9 of 19 cases first [12]. The authors described this technique as successful, but what would the success rate and patient comfort have been with the use of ultrasound? Another large study reported puncture of the external iliac artery in 2.7%, CFA in 77.5% and SFA or profunda in 19.8% [5] which must be regarded as unacceptably high.

A randomized study of palpation compared to fluoroscopic guidance found a reduced rate of low punctures (15 vs. 9%) but an equal number of high punctures (<1%) [7]. Abandoning palpable landmarks and using fluoroscopy to find bony landmarks as a puncture technique has been shown to reduce the risk of puncture-related complications such as pseudoaneurysm [4], but another study found that although this technique did reduce the number of low punctures, this did not result in reduced complications [1]. Fluoroscopic planning compared to palpation has also been shown to significantly improve the rate of ideal puncture in a cohort of patients with a BMI of greater than 30 (69 vs. 50%, $P = 0.02$) [9].

One randomized trial using ultrasound showed no benefit, but this may be due to learning curve and lack of familiarity of the operators with ultrasound guidance technique [3]. A review of a group of 273 patients with post-angiographic pseudoaneurysms and found that these occurred in 4.5% of patients who underwent access using traditional palpation, and only 2.6% in those undergoing ultrasound guided puncture [5]. Over time, it appears that operators have moved along a technological spectrum; from palpation of landmarks, to fluoroscopy of landmarks, to true image guidance with a combination of fluoroscopy and ultrasound. A further technique preferred by some operators is the use of Doppler activated needles which provide audible feedback, however the site of puncture often still cannot be determined and there is little evidence or logic to support their use over ultrasound.

Fluoroscopy is important to identify bony landmarks and ultrasound-guidance is the only method, which allows visualization of the femoral bifurcation. The combination of fluoroscopy to identify entry point, ultrasound-guidance to identify the femoral bifurcation and soft tissue compression to improve puncture geometry are critical for safe femoral arterial access.

This study provides further evidence of the anatomical variation at this important site and highlights the problems of dogmatic puncture techniques, particularly in light of puncture geometry as affected by an increasingly obese population.

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