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EDITORIAL COMMENT: Expert Article Analysis for:
Redefining landmarks to improve #safefemoral outcomes

Redefining the fluoroscopic landmarks for common femoral arterial puncture during cardiac catheterization: Femoral angiogram and computed tomography angiogram (FACT) study of common femoral artery anatomy

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Abstract

Background: The mid-femoral head (F_{50}) is a common fluoroscopic target for common femoral artery (CFA) puncture during cardiac catheterization. Punctures above the inguinal ligament (marking the proximal end of CFA) increase the risk of retroperitoneal hemorrhage and are classified as high punctures.

Methods: We retrospectively analyzed 114 CT angiograms for the anatomic relationship of the inguinal ligament to the femoral head (FH) and inferior epigastric artery (IEA). We analyzed 114 CT angiograms and 500 femoral angiograms, for the relation of the mid-point of CFA to F_{50} and F_{75} (the junction of upper 3/4th and lower 1/4th of FH).

Results: The proximal third of femoral head (F_{33}) (−1.4 mm) and IEA nadir (−2.9 mm) were closer approximations to the inguinal ligament than the IEA origin (−12.8 mm) or cranial end of FH (−15.2 mm). The inguinal ligament correlated better with the IEA nadir than F_{33} (R^2 = 0.49 vs. 0.001). F_{75} was a closer approximation for the mid-point of the CFA than F_{50} (0.3 mm vs. -9.2 mm). Using F_{75} as the target for CFA puncture carried the lowest risk for non-CFA punctures (18.6%), while using F_{50} had a 41.2% risk for non-CFA punctures. F_{75} had an increased risk for low punctures (14.2%) but F_{50} had a far higher risk for high punctures (36.6%).

Conclusions: The nadir of IEA is the best landmark for identifying the inguinal ligament (the proximal end of CFA) and defining high punctures. F_{75} is a more accurate target for successful CFA puncture than F_{50}.

KEYWORDS

access site complications, high puncture, low puncture, vascular access

1 | INTRODUCTION

With over a million procedures performed annually in the United States, cardiac catheterization plays a singular role in diagnosis and treatment of coronary artery disease. Vascular access site complications are the most common complications during cardiac catheterization.[1] Despite the advantages of the femoral approach (relatively more predictable anatomy, ability to use large sheath sizes for complex interventions), the transradial approach is increasingly preferred due to a lower incidence of access site complications.[2] The increasing adoption of a "radial-first" approach may increase femoral complications if femoral

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expertise is diminished[3]. While radial access is increasing, the femoral approach remains the predominant access site for cardiac catheterization.[4,5] Structural heart procedures and ventricular support devices require large sheath sizes and are primarily performed using femoral access.[6]

Access site complications increase mortality risk.[7] The incidence of access site complications is lower if the arteriotomy is within the common femoral artery (CFA). The CFA is defined anatomically as the extension of the external iliac artery caudal to the inguinal ligament and cranial to the CFA bifurcation into the superficial femoral artery and profunda femoris artery.[1,8] The CFA is usually anterior to the medial third of the femoral head (FH), and manual compression against the FH is standard for arterial hemostasis. The inguinal ligament courses caudally and medially from the anterior superior iliac spine to the pubic tubercle. The inguinal ligament marks the proximal end of the CFA. Arteriotomy above the inguinal ligament is categorized as a high puncture, and associated with a markedly increased risk of retroperitoneal hemorrhage (RPH) as the artery is retroperitoneal at this level.[1,8] Arteriotomy below the distal end of the CFA is categorized as a low puncture, and associated with a higher risk for pseudoaneurysm and arteriovenous fistulae.[1,8]

1.1 | Fluoroscopy during femoral catheterization

1.1.1 | Target for arterial puncture

The FH is the commonly used fluoroscopic landmark for CFA puncture.[9,10] A frequently recommended target site for arteriotomy in the vertical (cranio-caudal) axis is at the level of the mid-femoral head (F_{50}), i.e., midway between the superior and inferior borders of the FH.[1,11–15] This recommendation is based on the prediction that this location minimizes both high punctures and low punctures.[1,12,13]

1.1.2 | High puncture analysis

The inguinal ligament is a radiolucent soft tissue structure and cannot be visualized during fluoroscopy, but is visible on computed tomography (CT). Hence several surrogates have been used to identify the level of the inguinal ligament and recognize high-punctures during cardiac catheterization. Historically, the origin of inferior epigastric artery (IEA), the last branch from the external iliac artery, has been used to demarcate the transition to the CFA.[16] The IEA often arises proximal to the inguinal ligament and has an initial caudal and medial course before it loops cranially at the level of the inguinal ligament. The most caudal portion (nadir) of the IEA course has been suggested to correspond more reliably to the inguinal ligament and thus may be a better landmark for identifying high punctures.[17,18] The cranial end of the femoral head (F_0) and proximal third of the femoral head (F_{33}) are other landmarks that have been suggested for defining high punctures.[19–21] (Figure 1).

Using a cohort of patients with CT angiograms and a cohort of patients with conventional angiography, our objectives were to: (1) define CFA anatomy relative to the FH, (2) identify the most reliable fluoroscopic landmark for successful CFA puncture, and (3) identify the most reliable angiographic or fluoroscopic landmark for defining high punctures.

2 | METHODS

2.1 | CT angiography

CT angiograms performed in consecutive patients undergoing transcutaneous aortic valve replacement (TAVR) were analyzed for points of interest in the right CFA in relation to the FH (Figure 1) along the vertical or cranio-caudal axis. CT angiograms with inadequate visualization of the CFA course were excluded. The inguinal ligament was easily visualized and the exact location of the proximal end of the CFA, where the artery intersects with the inguinal ligament, was identified and compared against the FH in the transverse plane.

2.2 | Femoral angiography

We retrospectively reviewed consecutive femoral angiograms of patients who underwent femoral cardiac catheterization. Only procedures which met the following criteria were included: femoral angiography performed as part of a cardiac catheterization; complete visualization of the FH (both cranial and caudal margins of the FH being clearly visible); complete visualization of the CFA (visualization of the origin of the IEA proximally and femoral bifurcation distally). As the inguinal ligament cannot be visualized by angiography, we used the nadir of IEA as the surrogate for inguinal ligament (the CT portion of this study demonstrated the nadir of IEA to be the best surrogate for intersection of inguinal ligament with CFA). The nadir of the IEA and femoral bifurcation (the distal end of the CFA) was compared against the FH in the transverse plane. Measurements were obtained with quantitative angiography calibrated against the sheath size. The distances between the points of interest were measured in the vertical (cranio-caudal) axis. Hence significant cranial or caudal C-arm angulations may introduce parallax error. Femoral angiograms with cranial or caudal angulation greater than 10° were excluded. For a secondary analysis, cranial or caudal angulation was restricted to less than 5°. Right anterior oblique (RAO)/left anterior oblique (LAO) angulations do not impact parallax in the vertical axis and were not recorded. All patients had femoral angiograms performed in RAO (typically 20°–30°) projection with some patients having an additional LAO projection. Only the RAO projections were analyzed.

2.3 | Vascular anatomy encountered in the fluoroscopic window

The FH was divided cranio-caudally into the following zones (based on tertiles—1/3rds and quintiles—1/5ths of the FH), for analysis as potential fluoroscopic landmarks or windows for CFA puncture. From the most cranial border of the FH, points were labeled as a percentage of the length to the caudal border of the FH (F_0, F_{33}, F_{50}, F_{75}, F_{100}, etc.). We hypothesized F_{75} (the junction of upper 3/4th and lower 1/4th of the FH) would be a better target for CFA puncture than F_{50}. *Constructed tertile and quintile zones* centered on F_{75} were analyzed as well (Figure 1).

- *Tertile zones*: T1, T2 (T_{50}), T3 and T_{75}. The tertile zone T2 (T_{50}) is centered on F_{50}, the traditional landmark for CFA puncture. T_{75} is

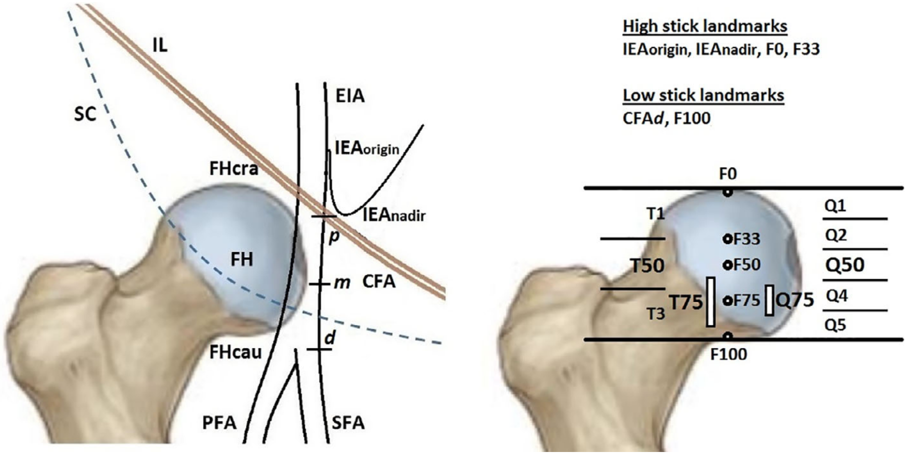

FIGURE 1 Common femoral artery anatomy and fluoroscopic landmarks. A, Relation of common femoral artery to femoral head and inguinal ligament. IL: inguinal ligament; SC: skin crease; FH: femoral head; FH cra: cranial end; FH cau: caudal end; EIA: external iliac artery; IEA: inferior epigastric artery; CFA: common femoral artery; PFA: profunda femoris artery; SFA: superficial femoral artery; *p*: proximal; *m*: mid; *d*: distal. B, Fluoroscopic windows based on different zones of femoral head. Points as a percentage of the length from the most cranial border of the femoral head to the caudal border of the femoral head—F0, F33, F50, F75, and F100. Tertile zones: T1, T50, and T3; quintile zones: Q1, Q2, Q50, Q4, and Q5; constructed zones centered on F75: T75 and Q75

a *constructed tertile zone* centered on F_{75}, our proposed landmark for CFA puncture.

- *Quintile zones*: Q1, Q2, Q3 (Q_{50}), Q4, Q5, and Q_{75}. The quintile zone Q3 (Q_{50}) is centered on F_{50}. Q_{75} is a *constructed quintile zone* centered on F_{75}.

In the invasive femoral angiogram cohort, patient-level analysis was performed for each of the tertile and quintile zones. In the CT angiogram cohort, tertile zones—T50 and T75 and quintile zones—Q50 and Q75 were analyzed.

2.4 | Statistics

Data were analyzed using SPSS version 25. The R^2-statistic was calculated to assess correlation between the inguinal ligament and its surrogates. The Bland–Altman analysis was performed for the surrogates for the inguinal ligament and the mid-point of the CFA.

3 | RESULTS

A total of 136 TAVR CT angiograms were reviewed. Twenty-two patients were excluded (poor contrast opacification—9; significant beam hardening artifacts from hip prosthesis—7; CFA not imaged—5; extracorporeal membrane oxygenation cannula precluding analysis—1), leaving 114 CT angiograms in the analysis. A total of 520 consecutive femoral angiograms which met the inclusion criteria were analyzed. Twenty patients with cranial/caudal angulations greater than 10° were excluded. Cranial/caudal angulations were less than 7.5° in 470 patients and less than 5° in 395 patients. Patients in the CT angiogram cohort were in general older than the patients in the invasive femoral angiogram cohort. Both cohorts were overwhelmingly Caucasian (95%). The femoral angiogram patients had a higher incidence of smoking and comorbidities in general except for hemodialysis, which was higher in the CT angiogram cohort (Table 1).

3.1 | Analysis of proximal end of CFA (to identify high-punctures)

The IEA nadir was more than 5 mm below the IEA origin in 71% of patients in the CT angiogram cohort and 61% in the invasive angiogram cohort. The CTA cohort demonstrated that F_{33} and the IEA nadir were closer approximations to the inguinal ligament compared with the origin of the IEA and the cranial end of the FH (Table 2, Figure 2).

TABLE 1 Demographic characteristics of femoral angiogram and CT angiogram patients

	Femoral angiogram	CT angiogram
Number of patients	500	114
Age (yrs)	66 ± 12 (27–94)	80 ± 8.8 (57–95)
Sex		
Male	58%	39%
Female	42%	61%
Body weight (kg)	90 ± 21 (41–190)	79 ± 20 (43–145)
Height (m)	1.7 ± 0.1 (1.4–2.1)	1.7 ± 0.1 (1.4–1.9)
Body mass index	30.9 ± 6.9 (15–60.1)	28.7 ± 6.2 (15.9–55.6)
Race		
Caucasian	95%	95%
African American	4%	5%
Others	1%	0%
Smoking	53%	21%
Hypertension	75%	73%
Diabetes mellitus	32%	29%
Peripheral vascular disease	18%	10%
HFrEF	30%	19%
HFpEF	26%	18%
Chronic kidney disease	13%	11%
Hemodialysis	1.4%	5.3%

Abbreviations: HFrEF, heart failure with reduced ejection fraction; HFpEF, heart failure with preserved ejection fraction.

In addition, the nadir of the IEA had the best correlation to the inguinal ligament (R^2 = 0.49) compared to the origin of the IEA (R^2 = 0.17) or F_{33} (R^2 = 0.001) (Figure 3). To define the location of the inguinal ligament and its surrogates, we used the cranial end of the FH as the point of reference. As expected, F_{33} had a fixed relation with the cranial end of FH (the point of reference). On the contrary, the inguinal ligament and its angiographic surrogates, that is, the origin and nadir of the IEA, had a variable relation to the cranial end of the FH. As the caudal displacement of the inguinal ligament in relation to the cranial end of the FH increased, the origin and nadir of the IEA also were more caudally displaced with the nadir of the IEA having a stronger correlation. On the contrary, F_{33} continued to have fixed relation to the cranial end of FH, without any correlation to inguinal ligament. Thus, while F33 may be slightly closer to the inguinal ligament in the overall cohort, on an individual patient level the nadir of the IEA correlated better with the inguinal ligament. The Bland–Altman analysis also demonstrated that the nadir of the IEA had the best combination of proximity to and predictability of the inguinal ligament location (Supplemental Figure S1).

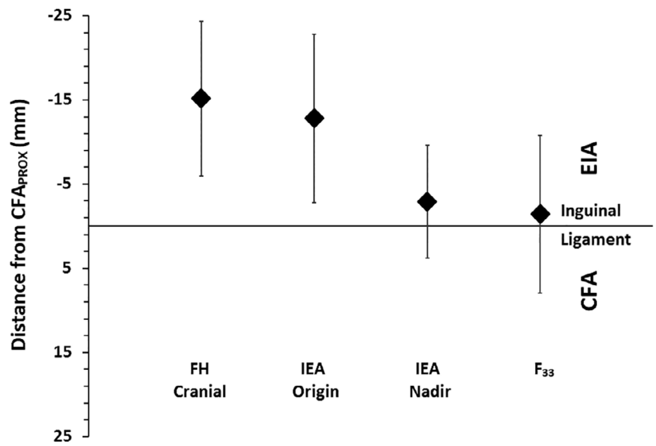

FIGURE 2 Distance between anatomic proximal end of CFA and its angiographic and fluoroscopic surrogates in CT angiogram cohort. Comparison of distances of F_0, F_{33}, IEA origin and IEA nadir from the proximal end of the CFA (the intersection of inguinal ligament and CFA). IEA origin and F_{33} are closer to the inguinal ligament than the other two surrogates. F_{33}: proximal third of femoral head; IEA: inferior epigastric artery; CFA: common femoral artery; EIA: external iliac artery; CFA_{PROX}: proximal end of CFA

3.2 | Analysis of mid-CFA (target for successful CFA arteriotomy)

The mid-point of the CFA was more proximate to F_{75} than to F_{50} (Table 2), and on average was at the level of 69% of FH vertical span in CT angiogram cohort and 76% of FH vertical span in invasive angiogram cohort (Figure 4). The Bland–Altman analysis of both the CTA and invasive angiogram cohorts also demonstrated that the mid-point of CFA was closer to F_{75} than F_{50} (Supplemental Figure S2).

3.3 | Analysis of likelihood of successful CFA puncture

The likelihood of non-CFA puncture at different tertile and quintile zones of the FH was analyzed (Table 3). In both the CT angiogram and femoral angiogram cohorts, the constructed tertile and quintile zones centered on F_{75} (T_{75} and Q_{75}) had the highest probability of successful CFA puncture (Figure 4, Supplemental Figure S3). Conversely, punctures at T_{50} and Q_{50} centered on F_{50} (the F_{50}—the traditional landmark for CFA puncture) had a higher risk for non-CFA punctures (mainly from an increased risk for high punctures). In the invasive angiogram cohort, a secondary analysis excluding angiograms with cranial/caudal angulations greater than 5° showed a similar result with T_{75} and Q_{75} having the highest probability for successful CFA puncture.

TABLE 2 Common femoral artery anatomy, relation to femoral head and landmarks

Parameter		Distance (mm)[a]
Length of CFA		37 (±12.1)
Caudal course of IEA after origin		6.7 (±6.2)
Distance of high puncture surrogates from anatomic proximal end of CFA[b]	F_0	−15 (±9)
	F_{33}	−1.4 (±9.3)
	Origin of IEA	−13 (±10)
	Nadir of IEA	−2.9 (±6.7)
Distance of fluoroscopic targets for CFA puncture from mid-CFA	F_{50}	−9.2 (±7.7)
	F_{75}	0.3 (±7.7)
Distance of caudal end of femoral head from femoral bifurcation		−5.3 (±11.3)

Abbreviations: CFA, common femoral artery; IEA, inferior epigastric artery; F_{50}, mid-femoral head; F_{75}, junction of upper 3/4th and lower 1/4th of femoral head.
[a] Negative distances mean the landmarks are cranial to point of interest and positive distance means landmark is caudal to point of interest.
[b] From CT angiogram cohort only.

4 | DISCUSSION

4.1 | High puncture analysis

To our knowledge, this study represents the largest and most comprehensive CT angiogram based study for defining CFA anatomy and high puncture analysis. While historically the origin of the IEA has been used for identifying high punctures during femoral cardiac catheterization, it is increasingly recognized as a less reliable marker than the nadir of the IEA. Sherev et al. found in 69% of patients, the inferior border of the IEA was inferior to its origin.[17] Similarly, the present results demonstrate that in the majority of patients the IEA had a caudal course with a nadir greater than 5 mm below its origin. The CT angiogram cohort clearly demonstrated that the nadir of the IEA was the most reliable predictor of the inguinal ligament, a finding that may resolve anatomical debates that could not be resolved without three-dimensional imaging. Using the origin of the IEA or the cranial end of the FH as landmarks for high puncture during femoral angiograms could lead to false adjudication of some high punctures as successful CFA punctures. This could potentially lead to less careful monitoring in these patients, off-label placement of closure devices, or increase the risk for development or delayed diagnosis of retroperitoneal hematoma.

The IEA typically courses both caudally and medially after its origin, before it loops cranially at the level of the inguinal ligament. When

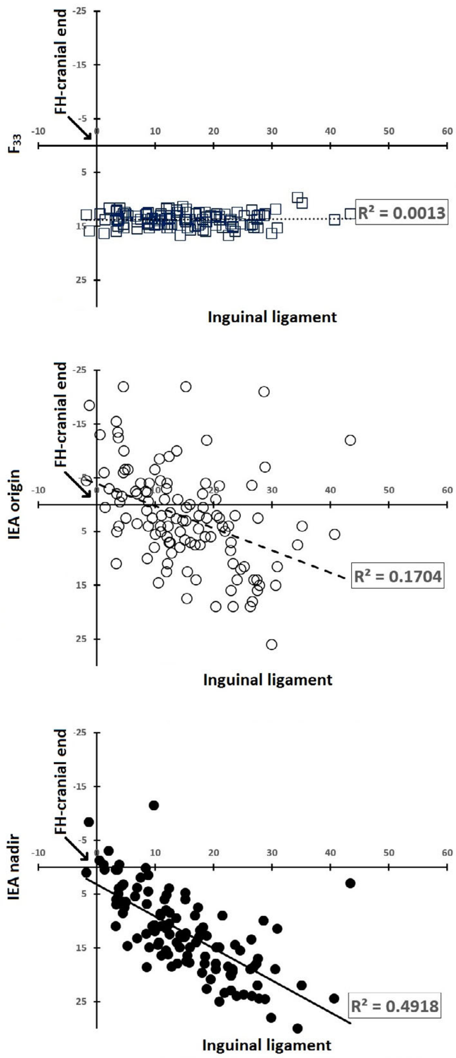

FIGURE 3 Correlation of the location of the inguinal ligament with its angiographic and fluoroscopic surrogates. Comparison of the location of the inguinal ligament with its different surrogates (IEA origin, IEA nadir and F_{33}) in individual patients relative to the cranial end of femoral head (FH-cranial end) in the CT angiogram cohort. Separation distances were measured in mm in the caudal direction. F_{33}: proximal third of femoral head; IEA: inferior epigastric artery; CFA: common femoral artery. (A) F_{33} vs. inguinal ligament had no correlation. F_{33} has a relatively fixed relation to the FH-cranial end while the relation of the inguinal ligament to the FH-cranial end varies for each patient. (B) Origin of IEA vs. inguinal ligament had a weak correlation. While the inguinal ligament is caudal to FH-cranial end in most patients, the IEA origin may be either cranial or caudal to FH-cranial end C. nadir of IEA vs. inguinal ligament had a stronger correlation. Both the inguinal ligament and the nadir of IEA were caudal to FH-cranial end in the majority of patients and the caudal displacement of both were to a similar extent

the nadir was 0–10 mm medial to the CFA (84 of 114 patients), the nadir was 4 (±6.8) mm above the inguinal ligament. When the nadir was 10–15 mm medial to the CFA (20 patients), it was 0.9 (±5.5) mm above the inguinal ligament. When the nadir was >15 mm medial to the CFA (nine patients), it was 2.4 (±4.7) mm below the inguinal ligament. In one patient where the nadir was lateral to the CFA, the nadir was 18.6 mm above the inguinal ligament. Thus, while the relation of

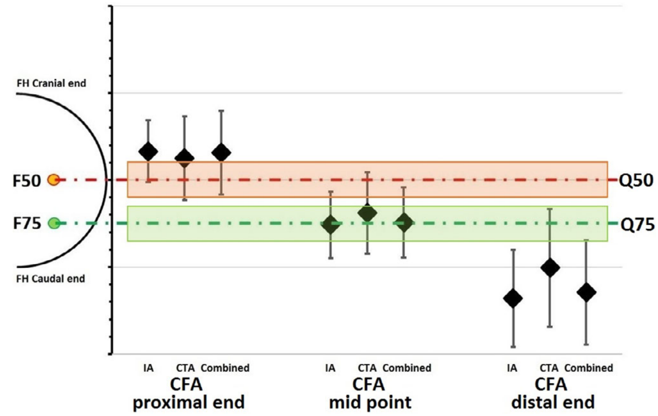

FIGURE 4 Relation of CFA to conventional and alternate landmarks for successful CFA puncture. Relation of proximal end, mid-point and distal end of CFA to femoral head among patients in the CT angiogram cohort, femoral angiogram cohort, and both cohorts combined together; F_{50}: mid-femoral head (conventional landmark); F_{75}: junction of upper 3/4th and lower 1/4th of femoral head (alternate landmark). Quintile zone Q_{50} (centered on F_{50}) has significant overlap with the proximal end of CFA resulting in increased risk for high punctures. Constructed quintile zone Q_{75} (centered on F_{75}) corresponds best to the mid-point of the CFA reducing the risk of non-CFA punctures

IEA nadir to the inguinal ligament can vary depending on how medial it is to the CFA, the IEA nadir still was a closer approximation to the inguinal ligament than the IEA origin even in patients where the IEA nadir was >15 mm medial to the CFA.

While our CTA findings suggest IEA nadir as the most anatomically accurate surrogate for inguinal ligament, there is limited data on its utility in estimating the risk for RPH. In punctures above the inguinal ligament, the artery is retroperitoneal and has a deeper course with the sheath passing through multiple intervening layers of anterior abdominal wall (superficial fascia and muscles).[16] While these are important factors in development of RPH, the presence or absence of underlying FH as bony support for manual compression may be a contributing factor as well. In studies looking at risk for RPH, high puncture has been defined variedly both in terms of relation to FH as well as IEA. Tremmel et al. compared the utility of F_{33}, IEA origin and IEA nadir for risk stratification for development of RPH in patients undergoing percutaneous intervention. The sensitivities of F_{33}, IEA origin and IEA nadir were 80%, 20% and 60% and positive predictive values (PPV) were 15%, 17%, and 18%, respectively.[20] Farouque et al. found a lower incidence of RPH in punctures below F_{33}.[22] Tiroch et al. found punctures above F_{33} were associated with higher risk for RPH.[19] Ellis et al. found femoral puncture above IEA origin to be the strongest correlate for RPH.[16] Punctures above the pelvic brim (above F_0) also strongly correlated with RPH. These studies suggest both factors—the relation of the puncture to the inguinal ligament and the presence or absence of underlying bony structure (FH), influence the risk for RPH. In the only head to head comparison of different surrogates for high puncture in predicting RPH risk, the incidence of high punctures was low ranging from 1 to 5% based on the criteria used.[20] The event rate for RPH was also low at 1% (only five cases) explaining the low PPV for all three surrogates.[20] Outcome studies with larger

TABLE 3 Likelihood of CFA and non-CFA punctures based on different fluoroscopic windows

Vessels seen in fluoroscopic window			CFA only			CFA + SFA/PFA			EIA + CFA			EIA + CFA + SFA/PFA		
RISK for High or Low Puncture			Minimal			Low Puncture			High Puncture			Both High & Low Punctures		
			IA (500)	CTA (114)	Combined (614)	IA (500)	CTA (114)	Combined (614)	IA (500)	CTA (114)	Combined (614)	IA (500)	CTA (114)	Combined (614)
Probability of CFA Anatomy Class based on bony landmark (%)	Tertiles	T1 0-33%	3.2			0.2			96.4			0.2		
		T_{50} 33-67%	**44.4**	**34.2**	**42.5**	**4**	**11.4**	**5.4**	**50.8**	**52.6**	**51.1**	**0.8**	**1.8**	**1.0**
		T3 67-100%	76.2			21.2			2.6			0		
		T_{75} 58-92%	**78.4**	**50.9**	**73.3**	**14.4**	**32.5**	**17.8**	**6.6**	**14**	**8.0**	**0.6**	**2.6**	**1.0**
	Quintiles	Q1 0-20%	3.2			0.2			96.6			0		
		Q2 20-40%	20.2			0.6			79			0.2		
		Q_{50} 40-60%	**60**	**53.5**	**58.8**	**3**	**7.0**	**3.7**	**36.4**	**37.7**	**36.6**	**0.6**	**1.8**	**0.8**
		Q4 60-80%	86			8.8			5			0.2		
		Q5 80-100%	78.4			21.2			0.4			0		
		Q_{75} 65-85%	**86**	**61.4**	**81.4**	**11**	**28.1**	**14.2**	**3**	**9.6**	**4.2**	**0**	**0.9**	**0.2**

Abbreviations: CFA: Common femoral artery; EIA: External iliac artery; SFA: Superficial femoral artery; PFA: Profunda femoris artery. IA: Invasive femoral angiogram; CTA: CT angiogram

sample sizes and larger number of events are needed to assess the relative utility of F_{33} and IEA nadir in predicting RPH. Ideally, a puncture below the IEA nadir (below inguinal ligament) as well as below F_{33} (ensuring bony support for manual compression) is ideal to avoid RPH. Regardless, at the time of arterial access, targeting F_{75} rather than F_{50}, is more likely to result in a puncture satisfying both the criteria for avoiding high punctures.

4.2 | Ideal target for CFA puncture

The F_{50} has been the traditional fluoroscopic landmark for CFA puncture.[11–13] Our study showed that the F_{50} has a higher risk for high punctures and that F_{75} (the junction of upper 3/4th and lower 1/4th of FH) had the highest probability for a successful CFA puncture. Reproducibility in two separate patient cohorts (from different institutions), using two different imaging modalities (CT and invasive angiography) increases the validity of our findings. In a study of 334 patients, Turi et al. reported a 92% probability of CFA puncture using a narrow zone 5 mm to 14 mm below F_{50}.[23] This zone is similar to the quintile zone Q_{75} described in our study which showed an 81% probability for successful CFA puncture.

4.3 | FACT and FAUST

The largest study of femoral anatomy comes from the FAUST study (989 patients) which recommended using the F_{50} as the landmark for CFA puncture. In the FAUST study, using the origin of the IEA to define a high puncture, the middle third of the FH had an 11% risk for high punctures.[14] Reinterpretation of the FAUST study data using the nadir of the IEA to define a high puncture demonstrates that T_{50} (middle third of femoral head) had a higher risk for non-CFA punctures (mainly high punctures). The lower third of femoral head (T3) had a lower risk for non-CFA punctures than T_{50} (Table 4). This further corroborates our conclusion that F_{75}, and not the mid-femoral head, is the ideal fluoroscopic landmark for CFA puncture. As Figure 4 (and Supplemental Figure S3) illustrates, for any particular point in the FH span the risk of a high-puncture is inversely proportional to the risk of low puncture. F_{75} appears to be the optimal target to balance the risks of high punctures and low punctures.

This study also illustrates the wide variation of CFA anatomy among patients (Figure 4). The nadir of the IEA was below the F_{50} in 92 patients (15%) and the femoral bifurcation was above F_{50} in 16 patients (3%). The nadir of IEA was below F_{75} in four patients (1%) and femoral bifurcation was above F_{75} in 56 patients (9%). Thus a perfect arterial puncture exactly at the level of F_{75}, still has a 10% chance of non-CFA puncture (compared with an 18% risk with puncture at the level of F_{50}). The addition of ultrasound guidance could potentially screen for these anatomic variations and further improve the chance of successful CFA puncture. The FAUST trial demonstrated improved CFA cannulation using ultrasound guidance in patients with high CFA bifurcation. In addition, it reduced both time to access and vascular complications. Thus, ultrasound and fluoroscopy may play a complementary role by avoiding low punctures and high punctures, respectively.

TABLE 4 Comparison of FAUST study and FACT study results

Risk for Non-CFA punctures (Based on tertile zones of Femoral Head)		n	Upper (T1) High-puncture	Upper (T1) Low-puncture	Upper (T1) Non-CFA puncture	Middle (T50) High-puncture	Middle (T50) Low-puncture	Middle (T50) Non-CFA puncture	Lower (T3) High-puncture	Lower (T3) Low-puncture	Lower (T3) Non-CFA puncture	T75 High-puncture	T75 Low-puncture	T75 Non-CFA puncture
FAUST[14]	IEA origin as High-puncture	989	65.9	0.8	**66.7**	10.8	5.1	**15.9**	0	31.1	**31.1**			
	IEA nadir as High-puncture		92.2	0.8	**93**	36.2	5.1	**41.3**	0.8	31.1	**31.9**			
FACT	Invasive angiogram	500	96.6	0.4	**96.8**	51.6	4.8	**55.6**	2.6	21.2	23.8	7.2	15	**21.6**
	CT angiogram	114				54.4	13.2	**65.8**				16.6	35.1	**49.1**
	Combined	614				52.1	6.4	**57.5**				9.0	18.8	**26.8**

Abbreviations: FAUST: Femoral Arterial Access with Ultrasound Trial[14], FACT: Femoral Angiogram CT Angiogram study

Our analysis suggests using the traditional landmark (T_{50}, middle third of FH), the risk for high puncture may be as high as 51%. However, this represents the highest theoretical risk for this tertile zone, corresponding to the risk when punctures are at the transition of T1 to T_{50}, that is, just below F_{33}. Within T_{50}, a more caudally placed puncture has a lower risk for high puncture with the risk approaching as low as 3% (same as risk for T3) when the puncture is at the transition of T_{50} and T3. Hence, clinicians tend to aim for the lower portion of T_{50} at the time of arterial access, as they are more wary of high punctures rather than low punctures. While the traditional recommendation for femoral access is arterial puncture midway between the cranial and caudal ends of the femoral head (F_{50})—Rupp's rule,[1,11] clinicians tend to avoid punctures above F_{33} (or even F_{50}). Analysis of arteriotomy in 160 consecutive patients of our FA cohort confirmed this practice pattern (Supplemental Figure S4). More than 75% of the punctures were below F_{50}. In theory, strict adherence to traditional teaching should have resulted in only about 50% of punctures below F_{50}. Frequency distribution analysis showed the punctures were all clustered around F_{75} rather than F_{50} (Supplemental Figure S4). Among the tertile zones, almost half the punctures were within T_{75} (49%). In comparison, only 35% punctures were in T_{50} suggesting conscious or subconscious bias among clinicians for a target lower than the traditionally recommended F_{50}. This may explain the low incidence of high punctures (1–5%) and RPH (<1%) in clinical studies.

Combining findings of previous studies showing increased risk for RPH with punctures above F_{33} and IEA nadir and data from our study suggesting F_{75} to be closer to midpoint of CFA than F_{50}, we suggest a modification to Rupp's rule.[1,11,19,20,22] At the time of access using fluoroscopic guidance, the arteriotomy should be targeted at the level F_{75} (instead of F_{50}) aiming to limit the eventual punctures to within a narrower range—F_{33} to F_{100}, rather than the traditional range of F_0 to F_{100} (Supplemental Figure S5). In addition, ultrasound can play a complementary role by identifying the femoral bifurcation at the time of arteriotomy to avoid puncturing SFA or PFA. At the time of femoral angiogram, an ideal CFA puncture should meet both criteria—(1) Below IEA nadir and above femoral bifurcation and (2) between F_{33} and F_{100} (Supplemental Figure S5). In addition, current practice patterns may be more aligned with our recommendation targeting F_{75} rather than the traditional target of F_{50}.

While findings of our CTA cohort suggest IEA nadir should be used to identify high punctures, impact of these findings on use of vascular closure devices (VCDs) is unclear. Data regarding safety of VCD use in non-CFA punctures are limited.[16] Data on performance of manual compression versus VCDs in preventing RPH in high punctures are conflicting.[16,17,20] Manufacturer prescribed instructions for use (IFUs) of commonly used VCDs, caution against their use in arterial punctures above the inguinal ligament or above the IEA nadir.[24,25] If the arteriotomy is above F_{33} and below IEA nadir, manual compression may be less effective due to lack of adequate bony support and VCDs may be considered as the puncture is likely below the inguinal ligament (Supplemental Figure S6). If the arteriotomy is below F_{33} and above the IEA nadir, likelihood of supra-inguinal puncture is high and reliability of VCDs is not clear as stated above and manual compression may be considered. If the puncture is above both IEA nadir and F_{33}, it represents the highest risk for RPH. This may warrant caution with anticoagulation use and dosing, in addition to close monitoring for development of RPH. Prospective studies are needed to evaluate if such a conceptual approach could lead to reduction in vascular complications. While VCDs are off-label for use in non-CFA punctures, there have been reports of successful use of VCDs in both high and low punctures.[26] Clinical studies on VCDs, using the anatomically accurate surrogate of inguinal ligament (IEA nadir) to define high punctures, are needed.

4.4 | Limitations

While our CTA cohort clearly established IEA nadir as the best anatomic surrogate for inguinal ligament, the impact of redefining high punctures on clinical outcomes such as RPH is uncertain, as previously noted. Parallax error can affect the interpretability of the femoral angiogram data, even though the magnitude of its effect on data interpretability has not been well studied.[15,27,28] A secondary analysis, excluding studies with cranial or caudal angulation more than 5° to minimize parallax effect, did not change the conclusion that F_{75} was a better fluoroscopic landmark than F_{50}. With reconstructions based on a three-dimensional dataset, CT angiography eliminates parallax error, and the findings in the present CT angiogram cohort mirrored the findings of the femoral angiogram cohort. Distances in femoral angiography represent indirect measurements using calibration with catheter size. This would affect the accuracy of individual measurements but as calibration error would affect all measurements for any given patient equally, the relative distances of different landmarks would remain valid. The CT angiographic measurements do not have this limitation, as distances were directly measured from a three-dimensional reconstructed dataset. Insofar as the inguinal ligament is a curved structure that courses in an oblique plane, the relationship between IEA nadir and proximal end of the CFA may vary based on the extent of medial displacement of IEA nadir from the CFA. The low puncture risk was slightly higher with F_{75}. While on average, the femoral bifurcation was slightly below the caudal end of the FH, its relation to FH varied among individual patients. Adjunctive imaging with ultrasound may further reduce the risk of low punctures. Both the invasive and CT angiogram cohorts were overwhelmingly Caucasian (95%). While significant racial disparities in CFA anatomy have not been reported,[14] the present findings may not be generalizable to non-Caucasian patients.

5 | CONCLUSION

The most caudal point in the course of the IEA (the nadir of the IEA) is a superior landmark for defining the inguinal ligament and CFA compared to the origin of the IEA. The junction of the upper 3/4th and lower 1/4th of the femoral head (F_{75}) is a better target for successful CFA puncture compared to the traditional landmark of the F_{50}. Improved understanding of femoral anatomy may improve the likelihood of successful CFA puncture and reduce vascular complications.

CONFLICT OF INTEREST

All authors declared that there is no conflict of interest.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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