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REVIEW ARTICLE

Clinical anatomy of the popliteal artery and its implications in total knee arthroplasty: a systematic review and meta-analysis

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Abstract

The popliteal artery (PA) is a lower extremity arterial vessel, a continuation of the superficial femoral artery. PA may be injured in the majority of total knee arthroplasty (TKA), as well as arthroscopic surgeries which may lead to acute ischemic injury. Our objective was analyzing morphometry of PA in relation to other structures both in flexion and extension of the knee, highlighting discrepancies in the PA's location in varying positions. Literature was reviewed in regards to morphological qualities, prevalence rates, and variants of PA were pooled. Five cadaveric and 14 radiological studies were included, totalling 1473 lower limbs. We found that PA, when nearing bone, was more predictable and fixed as seen in axial plane one and two centimeters distal to joint line at 0 degrees flexion. The distance between PA and posterior tibial cortex was estimated at 3.3 mm with 95% confidence interval (CI) 2.6–4.1 and 7.8 mm (95% CI 5.1–10.5) respectively. Once PA passed over and nearing the joint it had larger discrepancies with distance comparing the knee in 0 vs 90 degree flexion.

Due to rise of TKA, arthroscopic surgeries and connected vascular complications PA has been investigated more frequently, and while majority of publications describes relationships between vessels of popliteal area and specific landmarks conducted with knee in extension, our study also implemented data regarding knee flexion thus encompassing the problem in a more dynamic manner. We believe this provides superior data for identification of PA, especially during knee surgery.

Keywords: popliteal artery, total knee arthroplasty, meta-analysis, morphological variants, popliteal artery aneurysm, popliteal artery tear, arthroscopy

INTRODUCTION

The popliteal artery (PA) is a continuation of the superficial femoral artery, which is one of the primary supply of the blood to the distal lower extremity. It is located laterally in the intercondylar fossa, going through the adductor canal, then adductor hiatus, ending up at the medial part of popliteal fossa. Distally, it is running superficially and obliquely through the medial border of popliteus muscle, where it divides into the anterior and posterior tibial arteries [9, 31, 45, 51].However, it may divide just proximal to the popliteus muscle in its terminal branches, and in this case the anterior tibial artery sometimes descends anterior to the popliteus muscle [3, 15, 24, 26, 33]. From the clinical standpoint, PA is one of many accessible arterial pulse sites, and any practitioner can easily locate it in the posterior compartment of the knee. Pulsation is best felt in the lower part of the fossa, where the PA is close to the cortex of the posterior tibia. More rare pathologies could incorporate femoral artery obstruction, popliteal aneurysm and pseudoaneurysm. Moreover, many orthopedic procedures including total knee arthroplasty (TKA) may result in iatrogenic injury with the surgical saw, commonly during tibial cut and osteophytes removal from posterior tibia and distal femur leading either to aforementioned pseudoaneurysm or simply by cutting through the vessel [18].

In upcoming years the global demand for primary TKA is rising in a dramatic fashion and is expected to grow by 85% (1.26 million procedures) by 2030 [16]. Following this trend, it is important to remember about vascular injuries during this procedure. Based on the damage elicited and cause, we can classify the vascular injuries of the PA as: 1) Occlusion 2) PA transection by the surgical cut 3) Formation of arteriovenous fistula 4) Aneurysm or pseudoaneurysm formation. The mechanism for the first cause most commonly includes thrombosis, often caused by vascular wall damage [37]. However, it can be often met during application of tourniquet or thermal injury [37]. Yet another, however rare cause of arterial occlusion, is compression of the PA knee implant [24].

In case of aneurysms and much more common pseudoaneurysms, the mechanism includes either a partial tear on the arterial wall or indirect due to mechanical cutting during osteophyte removal or stretching and thermal injury from the cement [17].

Aforementioned complications following TKA have incidence rates ranging from 0.03% up to 0.51% [18], majority of them including PA [1]. Acute vascular insufficiency, which often immediately follows surgery, have been shown to have mortality and amputation rates of 7% and 42% respectively [28]. The aforestated vascular complications, as well as rising demand for both procedures can lead to an increased number of publications describing relationships between vessels of popliteal area and specific landmarks. However, there are only a few anatomical studies that are raising the issue of the relationship between the PA position in knee flexion and most of anatomic studies have been performed in knee extension. Those studies, which were done in knee flexion concentrated on the position of popliteal vessels in relation to tibial cuts, performed in high tibial osteotomy and TKA [12, 34, 40, 41, 44].

The aim of this study was not only to gather, but also to provide detailed clinical anatomy of the PA in different planes and positions, including the comparison of its length, diameter and course in relation to surrounding structures.

All of the aforementioned features were evaluated both in knee flexion and extension, thus highlighting their disparities. The following data can be especially useful for orthopedic surgeons during knee operations, as well as in clinical practice, because of the dynamic approach to our measurements.

MATERIALS AND METHODS

Search strategy

To identify the articles to include in the meta-analysis, an extensive search was performed through August 2022 in the following major electronic databases: PubMed, Embase, ScienceDirect, and Web of Science Core Collection. The search terms were identified after preliminary searches of the literature. No language or any other restrictions were applied to the database searches.

The following keywords were used in combination with Boolean operator, "OR" for the literature search: ("popliteal artery branching" OR "popliteal artery variations" OR "popliteal artery origin" OR "popliteal fossa vessel anatomy" OR "anterior tibial artery" OR "tibioperoneal trunk" OR "popliteal artery entrapment syndrome" OR "popliteal artery aneurysm" OR "popliteal artery morphometry"). References from all of the included articles were thoroughly searched to identify additional studies eligible for the meta-analysis.

Eligibility criteria

Articles eligible for inclusion into the meta-analysis were assessed by three independent reviews: Wiktor Raputa(WR), Izabella Świerczek (IŚ) and Jakub Ratusznik (JR). Studies that reported extractable anatomic data on the PA were included in the study. The following types of papers were excluded: case reports, case series, letters to the editor, conference abstracts, book chapters, review articles, and meta-analyses. There were no date or language restrictions applied. Any disagreements about eligibility of studies were solved by a consensus among all the reviewers, after consulting with the authors of the original study, by email, when necessary and possible.

Data extraction

Data from the included were individually extracted by three reviewers (WR, IŚ, JR) (Fig. 1).

Distance between the PA and the tibial insertion of the posterior cruciate ligament (PCL) at 90° of knee flexion

Distance between the PA and the posterior tibial cortex in the axial plane at 90° of knee flexion

Distance between the PA and the posterior tibial cortex in the sagittal plane at 90° of knee flexion

Distance between the PA and the trans-septal portal at 90° of knee flexion

Distance between the PA and the posterolateral portal at 90° of knee flexion

Length of the PA from the adductor hiatus to the femoral condyles

Length of the PA from the adductor hiatus to the origin of the anterior tibial artery

Length of tibioperoneal trunk

Diameter of the PA

Quality assessment

The Anatomical Quality Assessment (AQUA) tool and the Anatomical Quality Assurance (AQUA) Checklist were used to assess the quality and risk of bias in order to give strength to our meat-analysis. The Federative International Committee for Scientific Publications (FICSP) of the International Federation of Associations of Anatomists (IFFA) have endorsed the AQUA guidelines [19].

This review is reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [36]. This systematic review and meta-analysis was prospectively registered in PROSPERO (CRD42022359325).

Statistical analysis

Statistical analysis was performed by (WR, IŚ, JR) using Comprehensive Meta-Analysis (CMA) Software (Biostat, Englewood, New Jersey, United States). When assessing the weighted pooled means, the random-effects model was applied. The chi-square, X^2 and the Higgins I^2 statistic were used to probe for heterogeneity among the selected studies (Henry et al., 2016). Here, Cochrane's Q p-value of < 0.10 for the chi-square, X^2 test was used to indicate significant heterogeneity. To identify and measure heterogeneity, thresholds of the Higgin I^2 statistic were interpreted based on four categories: (1) a range between 0% and 40% was considered as "might not be important," (2) 30% and 60% as "may represent moderate heterogeneity," (3) 50% and 90% as "may represent substantial heterogeneity," and (4) 75% to 100% as "considerable heterogeneity" [20].

Subgroup analysis based on gender, type of study, side, laterality and geography was performed to probe for sources of heterogeneity. Next, 95% confidence intervals (95% CI) were compared to identify statistically significant differences between subgroups. If an overlap between the CIs was observed, the differences were considered statistically insignificant [20].

RESULTS

Study selection

A summary of the study identification process is shown in Figure 2. Suitable studies were collected accordingly to process visualized by Figure 2. We found a total of 27,977 articles from the database and 74 additional records from reference searching. After removing duplicates, the remaining 24,860 records were screened for eligibility on the basis of their titles and abstracts. 24,646 records were excluded as irrelevant to the meta-analysis, leaving 214 articles to be assessed on the basis of their full texts. 19 records were deemed eligible for inclusion into the meta-analysis. 21 case reports and case series, 6 conference abstracts, 4 letters to the editor, 1 book chapter, 4 review articles, and 1 meta-analysis were excluded on the basis of article type. 3 more were excluded for having incomplete data and 155 for lacking relevant and/or extractable data.

Study characteristics

The characteristics of the included studies are summarized in Table 1.

A total of 19 studies (n = 1476 lower limbs) were included in the meta-analysis. The study dates ranged from 1989 to 2020. The study types included cadaveric and radiologic imaging; including arteriography, magnetic resonance imaging (MRI), computed tomography, and Doppler ultrasound studies. The geographic origin of the studies included Asia, Europe, and North America (Fig. 2).

Morphometric analysis of the PA

The popliteal arteries were measured for their length, diameter, and orientation to surrounding structures in both 0 and 90 degree flexion. The estimated length of the PA from the adductor hiatus to the origin of the anterior tibial artery, and to the femoral condyles was 165.3 mm (95% CI 115.3–215) and 170.1 mm (95% CI 107.4–232.7) respectively. The estimated length of the Tibial-peroneal trunk was 34.8 mm (95% CI 26.2–43.3). At joint level the diameter of the PAwas estimated to be 7.2 mm (6.5–8.0) and when assessing the diameter five centimeters distal to the adductor hiatus the estimated diameter was 9.3 mm (95% CI 7.1–11.6). Proximal to the PA's termination the estimated diameter was 5.9 mm (95% CI 5.2–6.5) (Table 2).

When assessing the distance between the PA and the tibial insertions of the PCL in 90 degree flexion (n = 33) the estimated distance was 8.1 mm (95% CI 6.7–9.4). In the axial and sagittal planes when looking from joint level at 0 degrees flexion, the distance between the PA and the posterior tibial cortex was 4.6 mm (95% CI 3.0–6.2) and 8.2 mm (95% CI 7.9–8.7) respectively. When the joint was at 90 degrees then the distance between the PA and the posterior tibial cortex was 10.7 mm (95% CI 4.5–17.0) and 10.8 mm (95% CI 6.5–15.1) respectively. In the axial plane one and two centimeters distal to the joint line at 0 degrees flexion the distance between the PA and the posterior tibial cortex was estimated at 3.3 mm (95% CI 2.6–4.1) and 7.8 mm (95% CI 5.1–10.5) respectively. In the sagittal plane two centimeters from the joint line at 90 degrees flexion the estimated distance between the PA and the posterior tibial cortex was 11.7 mm (95% CI 11.2–12.2). The estimated distance of the PA and the trans-septal portal, and the posterolateral portal in 90 degree flexion was 15.0 mm (95% CI 9.1–20.8) and 45.3 mm (95% CI 36.2–54.4) respectively.

DISCUSSION

This meta-analysis included the assessment of 19 studies (n = 1586 lower limbs) and describes the most up-to-date data on the morphometry of the PA, as well as its implications in most commonly performed procedures involving the knee. TKA is a procedure including the resection of a lesioned articular surface of the knee, including replacement of the lateral and medial femorotibial joints, as well as the patellofemoral joint. The new surfacing is made with the use of metal and polyethylene components. This procedure is burdened with a few complications some of which contain neurovascular injury, including PA transection. In a large systematic review conducted recently the most prevalent type of vascular complications following TKA incorporate pseudoaneurysms (45%), followed by occlusion (33%) and transections (14%), all of which included the PA [50]. However, the presented problem can be minimized by placing the knee in a 90 degree-flexed position, which as a concept has been shown to increase distance between the PA and posterior tibial cortex [7, 40, 41, 43], thereby decreasing the chance of injury to the artery. This statement can be confirmed by Ishii et al. (2023) [21] who found that, from all the possible variables, the posterior tibial cortex distance was mostly influenced by the angle of flexion. The same principle was confirmed in our study where the distance between the PA and posterior tibial cortex was more than two times in case of axial and almost one third (31%) longer in the sagittal planes in a 90 degree knee flexion. This theory has been disputed in a few publications including Zaidi et al. (1995) [51] and Eriksson et al. (2010) [11], both of which consisted of ultrasound sonography (USG) guided examination of patients. These studies raise certain important points, the first one concerning Zaidi et al. (1995) [51], is tied to the study method which involved patients lying on their sides directly leading to negations effects of gravity on the PA. The second point, regarding both, concerned the use of an ultrasound probe resulting in excessive tension and pressure elicited on tissues of the popliteal fossae. The results are even more controversial as the majority of volunteers examined by Shetty et al. (2003) [40] presented the behavior of PA moving away from the posterior tibial complex during the USG examination.

In our study the two previously described points were excluded from examination, thus giving less biased results. Last but not least, the majority of the studies included in our meta-analysis included imaging modalities other than ultrasound, thereby eliminating the two concerning points included in papers by Zaidi et al. (1995) [51] and Eriksson et al. (2010) [11].

Our analysis of the PA revealed the mean diameter at joint line level of 7.2 mm (95% CI 6.5–8.0), which became even larger 5 cm distal to the adductor hiatus increasing up to 9.3 mm (95% CI 7.1–11.6). Interestingly, similar results concerning the morphometric measurements of PA at the level of the joint, were reached by other researchers including Ozgur et al. (2009) [35], Debasso et al. (2004) [10], Sandgren et al. (1998) [39], Yoo et al. (2009) [49], Morris-stiff et al. (2005) [32], ranging 7.5 mm ± 1.3, 7.4 mm, 7.4 mm ± 0.9, 7.6 (2.4, 3.7–14.2) and 7.4 ± 1.3 mm respectively. Additionally, considering the rising diameter of the PA 5 cm distal to the adductor hiatus, Cross et al. (2000) [8] and Ozgur et al. (2009) [35] presented comparable tendencies, rising to 10.5 mm [+/– 2.2] and 8.2 mm [+/– 1.6] respectively. Furthermore, significant differences when comparing genders were reported in the included studies. Our study found that in the case of the female population their morphometry was much thinner in all aspects, including side and part of PA, than in the male population, and thereby could be harder to pinpoint knee surgery, including TKA. These results are straightforward from the anatomical point of view, as morphometric size variation between genders are present. The same principle plays a role in the case of vascular structures including the PA, which was also presented in case of other studies including Wolf et al. (2006) [46]. In terms of ethnicity, we found that PA at the joint level measured less in the Asian population with 6 mm (95% CI 6.0–7.4 mm) compared to the general population at 7.2 mm (95% CI 6.5–8.0 mm) respectively. We believe that the presented difference is related to the overall smaller size of the Asian population in comparison to Western populations [48]. The demonstrated morphometrics of the PA shouldn't only be considered as mere anatomical peculiarity, as it can be implicated in many procedures, some of which include TKA and osteotomies around the knee. Another point to keep in mind is that the current trends have led to an increased rate of injury of PA [22, 38, 42]. Apart from TKA, one of the most common orthopedic procedures of the knee include arthroscopy. Although PA injury during it is rare, it can be a devastating complication that can result in anything from occlusion, laceration and even to amputation [6, 13, 22, 47]. The Arthroscopy Association of North America has reported as many as 6 penetrating injuries in 118,000 knee arthroscopies [4, 5]. Specific cases of acute popliteal injury have been documented, occurring most often after lateral meniscectomy [22, 38]. Other arthroscopic procedures associated with PA injury include arthroscopic PCL reconstruction [47] or posteromedial portal placement after arthroscopic total synovectomy. This is why our study implemented the distance between posterolateral and transseptal portals, and the location of the PA. It was done in 90-degree knee flexion, so that it can directly correspond to the real, in-hospital settings. Our study confirmed that the distance between the PA and the posterolateral portal at 90° of knee flexion was 45.3 mm (95% CI 36.2–55.4), PA to transseptal portal at 90° of knee flexion 15 mm (95% CI 9.1–20.8), and the distance of PA to the tibial insertion of the PCL at the same angle at 8.1 mm (95% CI 6.7–9.4). Makridis et al. [29] found the mean distance from PA to posterolateral and transseptal portal 40.7 mm +/– 5.1 mm, and 18.0 +/– 3.8, respectively, and go on to describe that a 90-degree knee flexion is the safest position to establish transseptal and posterior arthroscopic portals. The authors of this study do not recommend creating posterior arthroscopic portals at a 30 degree angle. Furthermore, the position of a 120 degree knee flexion is practically safe to create transseptal, however not posterolateral portals as the chance of injuring the common peroneal nerve is high [29]. Matava et al. (2000) [30] concluded that the increase in knee flexion corresponds to a decrease, however, not a complete elimination of the risk of arterial injury, during PCL reconstruction. The main limitation of this meta-analysis is the overall domination of radiological studies over cadaveric ones, more than three to one. Moreover, the first type of studies is not a homogenous group as it comprises many modalities, which as we have shown in case of USG consists of many different ranges of biases. However, in our case three of the 14 radiological studies were ultrasonographic and almost half totalling a number of 6 were MRI.

In order to strengthen our meta-analysis the Anatomical Quality Assurance (AQUA) Checklist and the Anatomical Quality Assessment (AQUA) Tool were used to evaluate the risk and quality of bias. The AQUA guidelines have been endorsed by the Federative International Committee for Scientific Publications (FICSP) of the International Federation of Associations of Anatomists (IFFA) [19].

CONCLUSIONS

The PA and its clinical anatomy have been investigated in many publications earlier, however it was usually done with the knee in an extended position only. In this publication we additionally collected the data encompassing flexion, to imitate the situation during knee surgery. It is not only superior in providing more precise data, but also has a clinical tie-in, which is the description of the mean diameter, length and distance changes of PA from tibial cortex, thus providing important information for many anatomists, as well as residents and orthopedic surgeons with a precise tool in identification of this vessel.

Article information and declarations

Author contributions

Jakub R. Pękala — corresponding author, statistical analysis, conceptualization and study idea, work coordination, manuscript writing and revision, methodology.
Jonasz Tempski — manuscript writing and revision, data extraction.
Eirik Krager, J — manuscript writing and revision.
Jakub Ratusznik — literature search, data extraction.
Wiktor Raputa — literature search, data extraction.
Izabella Świerczek — literature search, data extraction.
Przemysław A. Pękala — work coordination, manuscript writing and revision, methodology.
Jerzy A. Walocha — work coordination, conceptualization and study idea, methodology.

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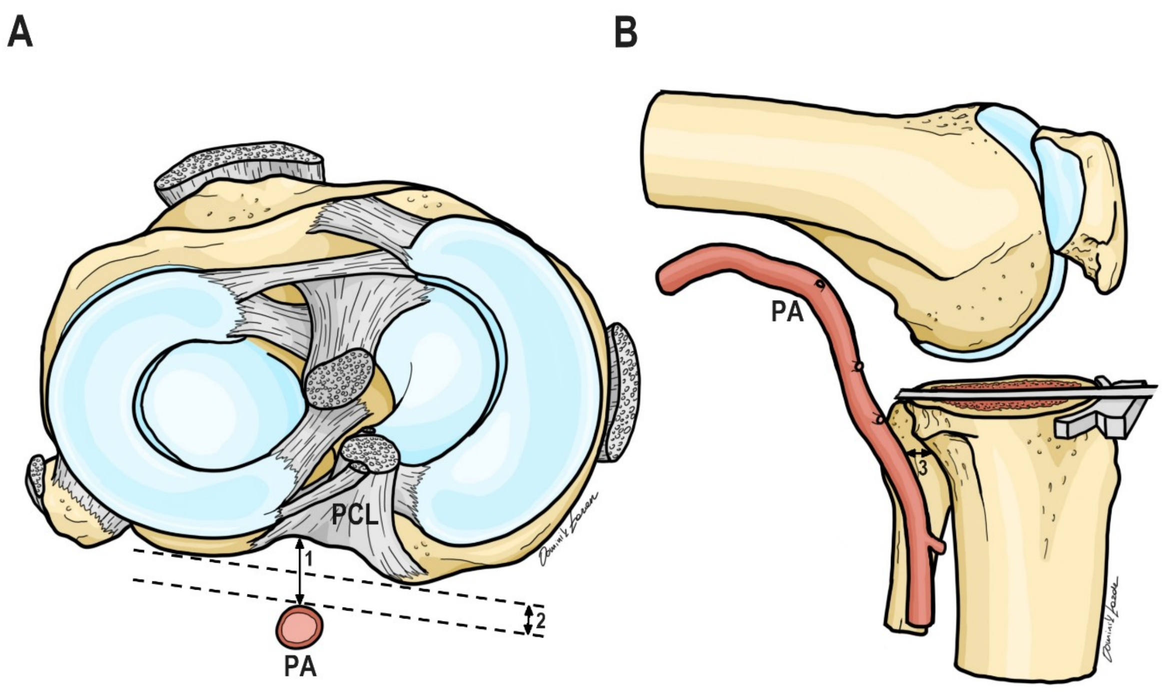

Figure 1. Popliteal artery (PA) in relation to tibial plateau and posterior cruciate ligament (PCL). 1 — distance between the PA and the tibial insertion of the PCL; 2 — distance between the PA and

the posterior tibial cortex in the axial plane at the joint line; 3 — distance between the PA and the posterior tibial cortex in the axial plane 1 cm distal to the joint line.

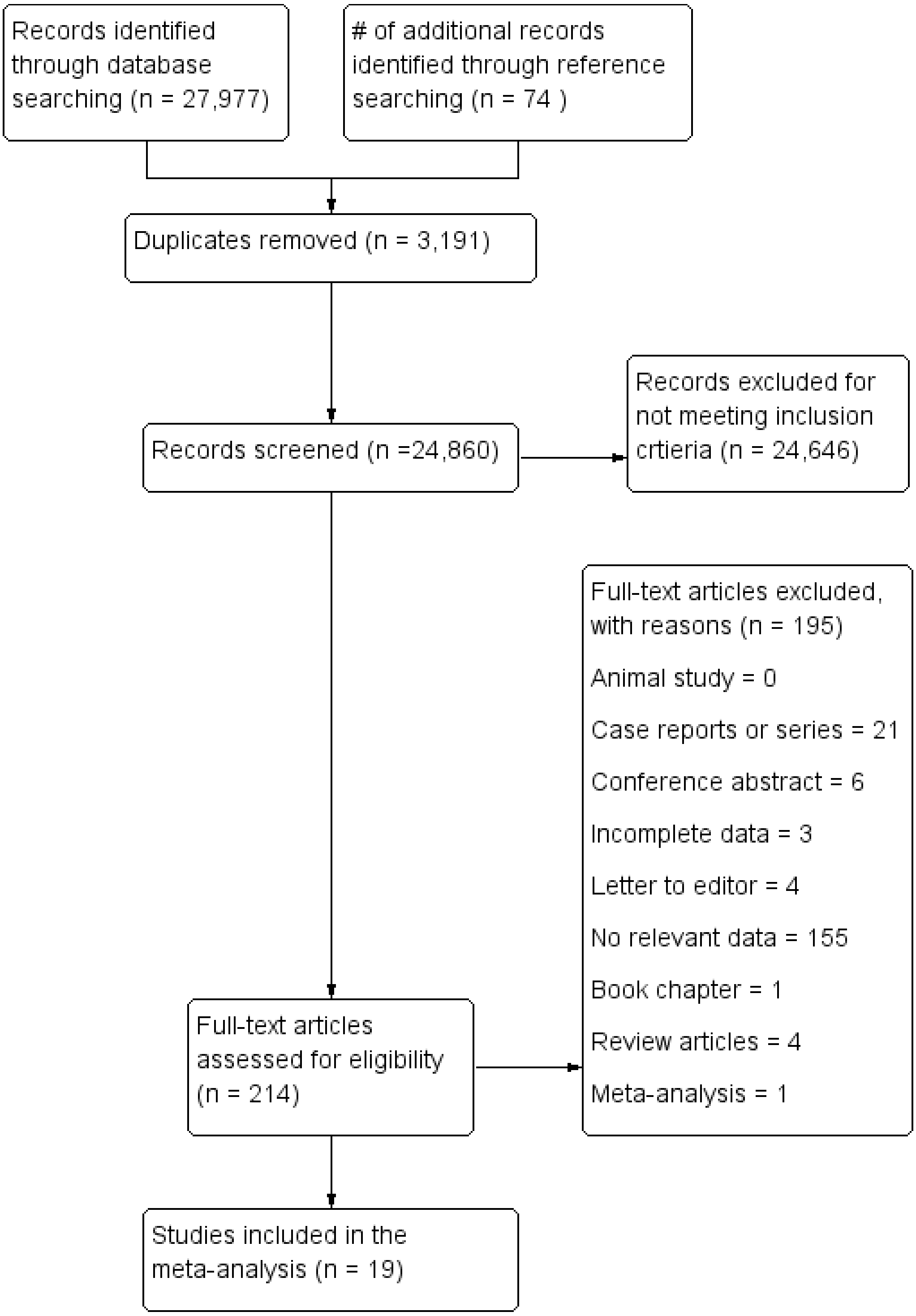

Figure 2. PRISMA flow chart of included studies

Table 1. Characteristics of included studies

Study	Country	Type of study	*n* = lower limbs
Ahn et al., 2007	South Korea	Radiological (Angiography)	10
Cancienne et al., 2017	United States	Radiological (Fluoroscopy)	8
Cosgarea et al., 2011	United States	Radiological (MRI)	9
Cross et al., 2000	United States	Cadaveric	51/52*
Darnis et al., 2014	France	Radiological (Fluoroscopy)	6
de Araujo Goes et al., 2015	Brazil	Radiological (MRI)	100
Eriksson & Bartlett, 2010	Australia	Radiological (USG)	80
Gajbe et al., 2020	India	Cadaveric	51
Hölzle et al., 2011	Germany	Cadaveric	256
Kim et al., 2010	South Korea	Radiological (Angiography)	7
Kim et al., 1989	United States	Radiological (Angiography)	220
Makridis et al., 2013	France	Cadaveric	17
Matava et al., 2000	United States	Radiological (MRI)	14
Ozgur et al., 2009	Turkey	Cadaveric	38/40*
Shetty et al., 2003	United Kingdom	Radiological (USG)	100
Shiomi et al., 2001	Japan	Radiological (MRI)	15
Wolf et al., 2006	Israel	Radiological (USG)	408
Yang et al., 2011	China	Radiological (MRI)	50
Yoo & Chang, 2009	South Korea	Radiological (MRI)	30

*The number of legs varied depending on the parameter that was measured; MRI — magnetic resonance imaging; USG — ultrasound sonography.

Table 2. Morphometric parameters of the popliteal artery

Morphometric parameter	Flexion [°]	Subgroup	No. of studies (No. of lower limbs)	Distance [mm] (95% CI)	I2 [%]
Distance between the PA and the tibial insertions of the PCL	90	All	3 (33)	8.1 (6.7–9.4)	0
	90	North America	2 (23)	8.3 (6.7–9.9)	8.6
Distance between the PA and the posterior tibial cortex in the axial plane					
Joint level	0	Asia	4 (98)	4.6 (3.0–6.2)	94.8
	90	Asia	2 (48)	10.7 (4.5–17.0)	97
1 cm distal to the joint line	0	Asia	3 (83)	3.3 (2.6–4.1)	81.7
2 cm distal to the joint line	0	Asia	3 (83)	7.8 (5.1–10.5)	96.9
Distance between the PAand the posterior tibial cortex in the sagittal plane					
Joint level	0	All	3 (180)	8.2 (7.9–8.7)	90.8
Level of HTO	0	All	2 (200)	10.8 (6.5–15.1)	98.9
2 cm distal to the joint line	90	All	2 (13)	11.7 (11.2–12.2)	0
Distance between the PA and the trans-septal portal	90	All	2 (25)	15.0 (9.1–20.8)	93.8
Distance between the PA and the posterolateral portal	90	All	2 (32)	45.3 (36.2–54.4)	96.1
Length of the PA from the adductor hiatus to the femoral condyles		All	2 (91)	170.1 (107.4–232.7)	99.3
Length of the PAfrom the adductor hiatus		All	2 (91)	165.3	98.5

to the origin of the anterior tibial artery				(115.3–215.4)	
Length of the tibial-peroneal trunk		All	2 (258)	34.8 (26.2–43.3)	84.4
Diameter of the PA					
Joint level		All	4 (500)	7.2 (6.5–8.0)	98.8
		Asia	3 (448)	6.7 (6.0–7.4)	98.6
5 cm distal to the adductor hiatus		All	2 (92)	9.3 (7.1–11.6)	97
Proximal to its termination		All	8 (766)	5.9 (5.2–6.5)	99.4
		Cadaveric	6 (358)	6.3 (5.7–6.8)	97.7
		Asia	6 (510)	6.0 (5.1–6.9)	99.6
		Female	3 (222)	5.8 (4.2–7.4)	99.5
		Male	3 (288)	6.2 (4.7–7.7)	99.7
		Left side	3 (179)	6.2 (5.3–7.1)	98.2
		Right side	3 (179)	6.3 (5.4–7.3)	98

PA — popliteal artery; HTO — high tibial osteotomy.

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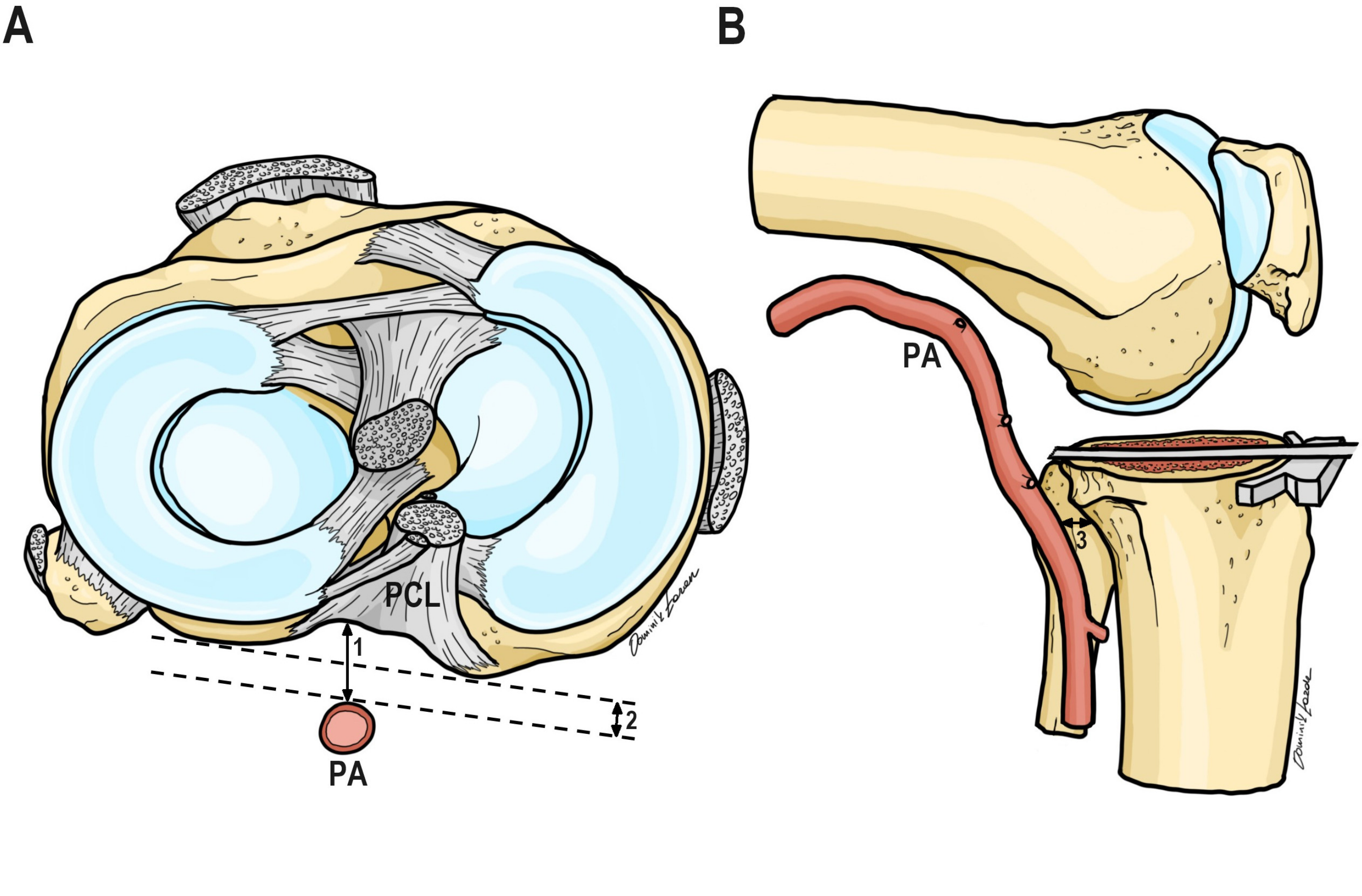
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PCL
1
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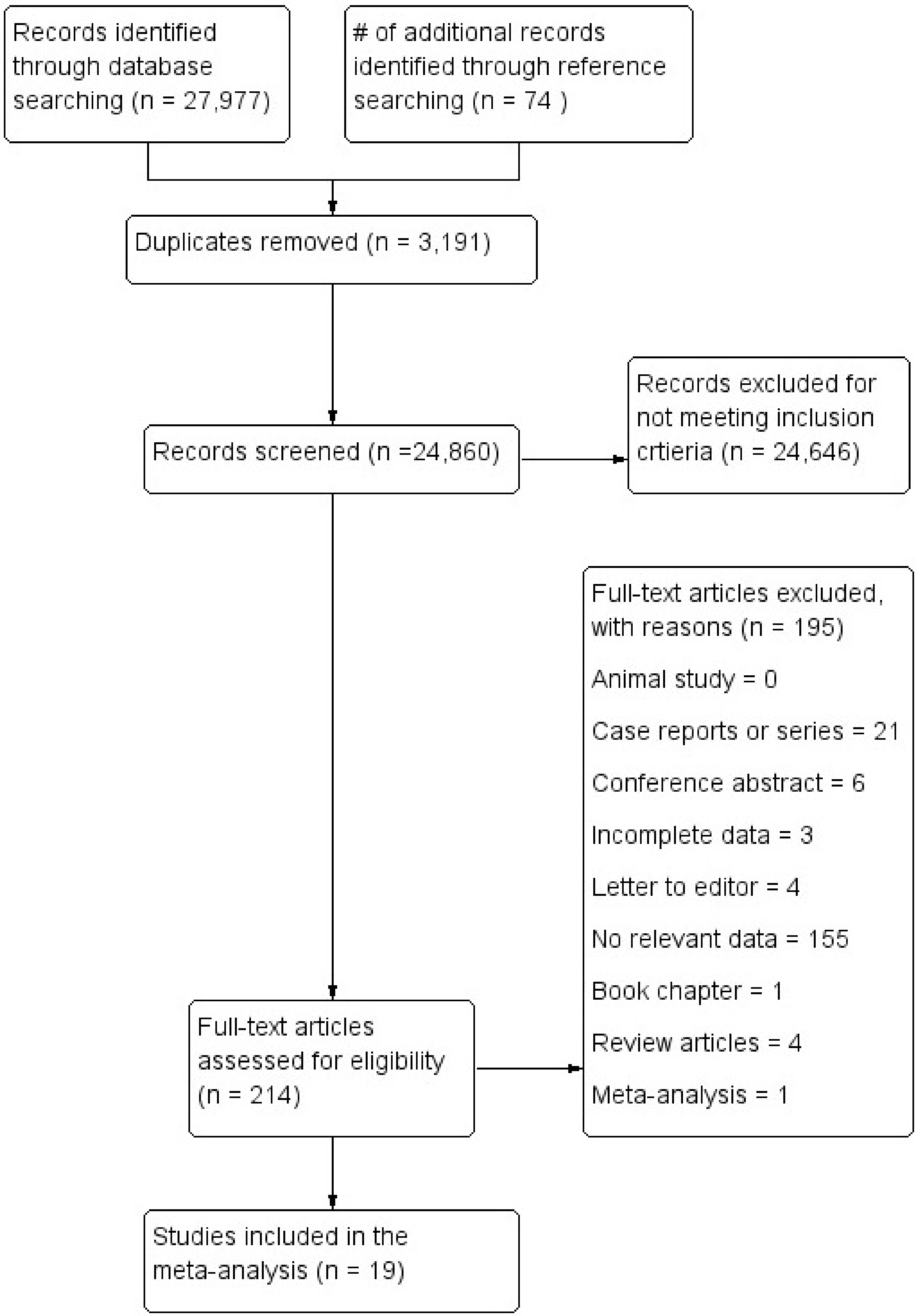
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Full-text articles excluded, with reasons (n = 195)
Animal study = 0
Case reports or series = 21
Conference abstract = 6
Incomplete data = 3
Letter to editor = 4
No relevant data = 155
Book chapter = 1
Review articles = 4
Meta-analysis = 1
Full-text articles assessed for eligibility (n = 214)
Studies included in the meta-analysis (n = 19)

Figure Legends

Figure 1 Popliteal Artery (PA) in relation to tibial plateau and Posterior Cruciate Ligament (PCL)

1- Distance between the PA and the tibial insertion of the PCL
2- Distance between the PA and the posterior tibial cortex in the axial plane at the joint line
3- Distance between the PA and the posterior tibial cortex in the axial plane 1 cm distal to the joint line

Figure 2 PRISMA flow chart of included studies

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