의학석사 학위논문

슬와 동맥 포착증후군에서 동맥협착과 연관된 해부학의 3 차원적 분석

Evaluation of 3-dimensional anatomy of popliteal artery entrapment syndrome in relation to the severity of arterial compromise

2015 년 2 월

서울대학교 대학원
의학과 영상의학 전공
김 민 욱

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지도교수 정진욱

이 논문을 의학석사 학위논문으로 제출함

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2015년 1월

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ABSTRACT

PURPOSE: To investigate the 3-dimensional (3D) anatomy of popliteal artery entrapment syndrome (PAES) in relation to the severity of arterial compromise.

MATERIALS AND METHODS: The lower extremity computed tomography (CT) angiograms of 22 patients (M:F = 21:1; mean age, 47.4 ± 19.9 years, 18~81years) with 31 limbs having PAES were retrospectively analyzed. Using a 3D workstation, two radiologists assessed the femoral attachment site of the medial head of the gastrocnemius muscle (MHGM) and determined whether the type of PAES was total or partial. Then, the degree of stenosis of the popliteal artery, the degree of medial displacement of the popliteal artery in the intercondylar space, and the distance from the inferomedial border of the MHGM attachment to the superolateral border of the medial femoral condyle (MHGM-condyle distance) were measured. Lesions with a stenosis of 50% or greater in diameter were considered significant. As an ancillary finding of PAES, the presence or absence of a retrocondylar fat pad sign was assessed. Thereafter, statistical analyses were performed to determine the relationship between the observed findings.

RESULTS: Among the 22 patients, 31 limbs had PAES (unilateral in 13 patients and bilateral in 9). Among the 31 limbs of PAES, the total type was found in 18 limbs (58.1%) and the partial type in 13 (41.9%). Significant stenosis of the popliteal artery was more frequently found in the total type than the partial type (94% vs. 38.5%, $p = 0.0016$). Popliteal artery stenosis was highly associated with the medial displacement of the popliteal artery (Spearman correlation coefficient = -0.726, $p < 0.0001$) and the MHGM-condyle distance (Spearman correlation coefficient = -0.556, $p = 0.001$). The total type showed more severe medial displacement of the popliteal artery (20.5 ± 10.0 vs. 57.4 ± 22.4, $p < 0.0001$) and shorter MHGM-condyle distance than the partial type (13.1 ± 4.6 vs 22.9 ± 7.2, $p =$

0.00038). The presence of a retrocondylar fat pad sign was more common in patients with significant popliteal artery stenosis than those without (91.0% vs. 33.3%, $p = 0.0024$).

CONCLUSION: The severity of popliteal artery stenosis in PAES was affected by the anatomical features related to the anomalous attachments of the MHGM. More severe stenosis can be expected in the total type, with more medial displacement of the popliteal artery in the intercondylar space, shorter MHGM-condyle distance, and a positive retrocondylar fat pad sign.

Keywords: Popliteal artery entrapment syndrome, Lower extremity,
CT angiography

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INTRODUCTION

Popliteal artery entrapment syndrome (PAES) is a rare cause of intermittent claudication mainly affecting young active men [1]. PAES is characterized by a developmental abnormality resulting from an abnormal relationship between the popliteal artery and the gastrocnemius muscle. Rarely is an anomalous fibrous band or the popliteus muscle thought to be the cause of PAES [2], [3]. The conventional classification of PAES described by Whelan and modified by Rich is currently accepted (Table 1). However, this classification should be challenged due to the inconsistent results between previous studies (Table 2) [4~13], probably caused by vague or incorrect interpretations of the classification. For instance, some investigators reported type 1 as dominant, while other investigators either did not observe type 1 or reported that it was uncommon. According to the classification, type 1 is defined as the medial deviation and aberrant course of the popliteal artery with normal insertion of the medial head of the gastrocnemius muscle (MHGM). Type 2 is defined as abnormal lateral insertion of the MHGM with the normal course of the popliteal artery. Considering that the attachment areas of the MHGM at the femur vary widely in location [14] and the popliteal artery is somewhat displaced and compressed by the MHGM, it seems difficult to discriminate between type 1 and type 2. There is also a significant discrepancy in the frequency of type 4.

In addition, the severity of the popliteal artery compromise in PAES can differ between the types and even within the same type. Thus, it will be clinically useful to identify the anatomical features that determine the severity of popliteal artery compromise. However, until now, no research has been conducted to investigate the detailed anatomical features determining popliteal artery compromise in PAES.

With the advent of helical computed tomography (CT) technology in sufficient submillimeter spatial resolution [15], [16], multidetector CT (MDCT) has enabled us to evaluate not only the status of peripheral arteries, but also their relationship to adjacent structures. Thus, in the era of MDCT, it is necessary to revisit and analyze the popliteal fossa structures to better understand PAES and identify significant anatomical features determining popliteal artery compromise. Therefore, this study was conducted to investigate 3-dimensional (3D) anatomical features of PAES in relation to the severity of arterial compromise.

MATERIALS AND METHODS

This study was approved by our institutional review board, and the need to obtain informed consent was waived due to its retrospective nature.

Patients

From January 2002 to December 2012, 37 patients reported as having PAES were retrieved from the PACS system. Among them, 15 patients were excluded from this study for one of the following reasons: (a) no availability for the 3D evaluation of a lower extremity CT angiography of a section less than 3 mm thin (n = 13); (b) underlying severe atherosclerosis (n = 1); and (c) severe metallic artifact due to total knee replacement arthroplasty (n = 1). Finally, 22 patients (21 men, 1 woman; age range, 18–81 years, mean age, 47.4 years) with 31 limbs with PAES and 13 normal limbs were included in the study. The symptoms and the duration were reviewed from electrical medical records.

Multi-detector CT Angiography Technique

CT examinations were performed using four different MDCT scanners: a 4-detector row unit (MX 8000; Philips Medical Systems, Cleveland, Ohio), an 8-detector row unit (Light Speed Ultra; GE Medical Systems, Milwaukee, Wisconsin), a 16-detector row unit (Sensation 16; Siemens, Erlangen, Germany), or a 64-detector row CT unit (Brilliance 64; Philips Medical Systems)

The patients were placed in the supine position with the feet positioned to enter the gantry first. The extremities were positioned with the knee and ankle joints in the neutral positions. An apparatus supporting an ankle and buttock was used to provide leg elevation and avoid compression of the veins and muscles of the posterior thigh and calf. After obtaining an initial scout image (tube voltage: 100 kVp, tube current: 50 mAs), the scanning ranges were planned on an individual basis from the third lumbar vertebra to the level of the foot. An 18- or 20-gauge catheter was placed into an antecubital vein, and 2 mL/kg of iopromide (Ultravist 370; Schering, Berlin, Germany) was injected with a power injector (Envision CT; Medrad, Indianola, PA) at a rate of 3 mL/s.

The scans were initiated from a level above 100 Hounsfield units of region of interest with 4- to 23-second delay, depending on scanning speed. The scanning parameters used for CT angiography were also altered to suit the scanner used. For the MX8000 scanner, the parameters were as follows: detector collimation, 4 x 2.5 mm; pitch value, 1.5:1 (15mm table feed per rotation); slice thickness, 3.2 mm; and reconstruction interval, 1.6 mm. For the LightSpeed Ultra scanner, the parameters were as follows: detector collimation, 8 x1.25 mm; pitch value, 1.3:1 (17.5 mm table feed per rotation); slice thickness,1.25 mm; and reconstruction interval, 1.25 mm. For the Sensation 16 scanner, the parameters were as follows: detector collimation, 16 x0.75 mm; pitch value, 1:1 (1mm table feed per rotation); slice thickness, 1.5 mm; and reconstruction interval, 1 mm. For the Brilliance 64 scanner, the parameters were as follows: detector collimation, 64 x0.625 mm; pitch value, 1:1 (1mm table speed per rotation); slice thickness, 1.5 mm; and reconstruction interval, 1 mm.

The scan range started above the iliac bifurcation and extended to the feet. All thin-section axial images were transferred to a workstation with a three-dimensional (3D) reconstruction software (Rapidia, INFINITT, Seoul, Korea).

Imaging Analysis

The two board-certified radiologists loaded the volume data into the 3D program and reviewed multiplanar images in a real-time interactive manner and reconstructed 3D images using a volume rendering technique. They assessed the femoral attachment site of the MHGM and determined whether the type of PAES was total or partial. Then, the stenosis degree of the popliteal artery, the degree of medial displacement of the popliteal artery in the intercondylar space, and the distance from the inferomedial border of the MHGM attachment to the superolateral border of the medial femoral condyle (MHGM-condyle distance) were measured.

As an ancillary finding of PAES, the presence or absence of a retrocondylar fat pad sign was assessed. Using a 2D/3D interactive visualization technique, the morphology and attachment site of the MHGM and its anatomical relationship with popliteal vessels was schematically drawn on 3D volume rendered images with bony landmarks (Fig. 1). Differences of opinion were resolved by consensus.

Attachment site of the MHGM at the femur

From the bottom to the top, the MHGM was carefully traced in an upward direction on axial images to assess whether it divides before femoral attachment. For precise localization of the femoral attachment site of the MHGM, we used a special 2D/3D interactive visualization technique to display axial and sagittal reformation images in real time at the cursor point indicated on a 3D volume rendered image. The morphology of the MHGM and its attachment site was schematically drawn on a volume rendered image expressing bony structures.

Type of PAES

We classified PAES into total type or partial type according to the morphology of the MHGM and its relationship with the popliteal artery. The total type was defined as total anomalous insertion of the MHGM with medial malposition of the popliteal artery (corresponding to type 1 and type 2 of the classification of Whelan modified by Rich). The partial type was defined as partial anomalous insertion of the MHGM (as an accessory slip or fibrous band) and medial malposition of the popliteal artery (corresponding to type 3 of the classification of Whelan modified by Rich) (Fig. 2).

Stenosis of the popliteal artery

The stenosis degree in diameter of the popliteal arteries was visually assessed. Lesions with a stenosis of 50% or greater in diameter were considered significant. A popliteal artery was considered occluded at 100% stenosis. The anatomical reason for popliteal artery stenosis was analyzed.

Medial displacement of the popliteal artery

The degree of medial displacement of the popliteal artery was evaluated by its relative position in the intercondylar space. The medial border of the lateral femoral condyle was set as the 100th point and the lateral border of the medial femoral condyle as 0th point. Consequently, it was possible to express the relative position of the popliteal artery in the intercondylar space as a value between 0 and 100 points (Fig. 3). The value is smaller with medial displacement of the popliteal artery.

The distance from the inferomedial border of the MHGM attachment to the superolateral border of the medial condyle (MHGM-condyle distance)

In PAES, the popliteal artery should pass through the space between the anomalous femoral attachment of the MHGM and the medial femoral condyle to enter into the popliteal fossa. Therefore, the space between the anomalous femoral attachment of the MHGM and the medial femoral condyle is a window for the popliteal artery to enter into the popliteal fossa. The smaller window may exacerbate the popliteal artery compromise. We measured the distance from the inferomedial border of the MHGM attachment to the superolateral border of the medial condyle (MHGM-condyle distance) (Fig. 4). A longer MHGM-condyle distance means that the anomalous MHGM shows more cranial and lateral femoral attachment.

Retrocondylar fat pad sign

With lateral displacement of the MHGM, a triangular-shaped fat pad may accumulate at the vacant space in the posterior medial compartment of the calf behind the femoral condyle (Fig. 5). We called it a “retrocondylar fat pad sign”. We visually assessed the presence or absence of a retrocondylar fat pad sign on axial CT scans at the level of the intercondylar fossa in each patient.

Statistical Analysis

Fisher's exact test was used for comparing proportional differences in the frequency of significant popliteal artery stenosis according to the type of PAES or according to the presence of a retrocondylar fat pad sign. The Mann-Whitney test was used to compare the differences in the degree of medial displacement of the popliteal artery according to the significance of popliteal artery stenosis, the differences in the MHGM-condyle distance according to the type, and the differences in the degree of medial displacement of the popliteal artery according to the type. The correlation between the medial displacement of the popliteal artery and popliteal artery stenosis, between the medial displacement of the popliteal artery and the MHGM-condyle distance, and between the MHGM-condyle distance and popliteal artery stenosis were analyzed using Spearman's rho rank correlation coefficients. All statistical analyses were performed using commercially available software (SPSS 17.0 for Windows; SPSS, Chicago, Illinois). A p value of 0.05 was considered a statistically significant difference.

RESULTS

Patient demographics and clinical presentation

The clinical symptoms of all patients are summarized in Table 3. Sixteen patients had symptoms related to arterial ischemia. Claudication was the most common ischemic symptom (14 patients, 63.6%). Four patients had symptoms unrelated to arterial ischemia, such as non-specific knee pain or deep vein thrombosis. The remaining two patients (9.1%) were asymptomatic.

Among the 16 patients with ischemic symptoms, only one patient presented with acute ischemia within two weeks of symptom onset. The other 15 patients had chronic symptoms.

The age of the patients with ischemic symptoms was 40 ± 15.8 years, and the age of the patients with no symptoms or unrelated to arterial ischemic symptoms was 67.2 ± 16.5 years. There was a statistically significant difference (p = 0.002).

Type of PAES

Nine (40.9%) of the 22 patients with PAES had bilateral abnormalities in both limbs. Thirteen (59.1%) patients had unilateral PAES. In 13 patients with unilateral PAES, the right limb was involved in 8 (61.5%) and the left limb was involved in 5 (38.5%). Among the total of 31 limbs with PAES, 18 (58.1%) had the total type and 13 (41.9%) had the partial type (Table 4).

There was a significant difference in the presence or absence of ischemic symptoms depending on the type of PAES (p = 0.0242). The total type had ischemic symptoms in 77% (n = 14/18) and the partial type in 30.7% (n = 4/13).

Attachment site of the MHGM at the femur

In all cases, the femoral attachment area of the MHGM was successfully identified and drawn as shown in Fig. 6. Substantial overlap was found in the femoral attachment area of the MHGM between the three groups of normal anatomy, the PAES of the total type and the PAES of the partial type. The MHGM with PAES showed relatively more cranial and lateral femoral attachment than the MHGM of normal limbs. In PAES, the MHGM of the partial type tended to have more cranial femoral attachment than that of the total type. In the partial type of PAES, the group without significant popliteal artery stenosis showed relatively more cranial femoral attachment of the MHGM than the group with significant stenosis.

Stenosis of the popliteal artery

The degree of stenosis of the popliteal artery according to the type of PAES is shown in Table 5. Significant stenosis of the popliteal artery was found in 17 (94.0%) of 18 limbs with the total PAES type. On the other hand, significant stenosis of the popliteal artery was found in 5 (38.5%) of 13 limbs with the partial PAES type. The difference was statistically significant (p = 0.0016). All popliteal arterial segments with stenosis had medial displacement due to anomalous MHGM. The anatomical reason for significant popliteal artery stenosis was the entrapment of the popliteal artery between the medial femoral condyle and the MHGM, with the exception of one patient with the partial PAES type. In that patient, the popliteal artery was entrapped between the split medial heads of the gastrocnemius muscle (Fig. 7).

Medial displacement of the popliteal artery

Table 6 summarizes the degree of medial displacement of the popliteal artery at the intercondylar space according to the type of PAES and the presence or absence of popliteal artery stenosis. Compared to normal limbs, popliteal arteries were more medially displaced in limbs with PAES (p < 0.0001). One limb with the total type and no significant popliteal artery stenosis also showed medial displacement of the popliteal artery. When compared with the total type, the partial type showed significantly less medial displacement of the popliteal artery (20.5 ± 10.0 vs. 57.4 ± 22.4, p < 0.0001) In the partial type of PAES, popliteal arteries were more medially displaced in limbs with significant popliteal artery stenosis than the limbs without (p = 0.0116). In addition, a significant correlation was observed between the degree of medial displacement and the degree of popliteal artery stenosis (Spearman's rho correlation coefficient, -0.726; $p < 0.0001$).

The distance from the inferomedial border of the MHGM attachment to the superolateral border of the medial condyle (MHGM-condyle distance)

There was a significant difference in the MHGM-condyle distance between the total type and the partial type (13.1 ± 4.6 mm vs. 22.9 ± 7.2 mm, p = 0.00038). In the partial PAES type, there was also a significant difference between the group with significant popliteal artery stenosis and those without (16.6 ± 4.8 mm vs. 25.4 ± 7.7 mm, p = 0.0455). In addition, a significant correlation was observed between the MHGM-condyle distance and the degree of stenosis of the popliteal artery (Spearman's rho correlation coefficient, -0.556; p = 0.001) and between the MHGM-condyle distance and the degree of popliteal artery displacement (Spearman's rho correlation coefficient, 0.552; p = 0.002).

Retrocondylar fat pad sign

A retrocondylar fat pad sign was observed in 23 (74.2%) of 31 limbs with PAES (Table 7). It was not observed at all in the normal limbs. In PAES, it was more frequently found in the total type (17/18, 94.4%) than in the partial type (5/13, 38.5%). It was most frequently observed in PAES with significant popliteal artery stenosis than without (91.7% vs. 33.3%, p = 0.0024).

Table 1. Classification of popliteal artery entrapment syndrome, by Whelan and modified by Rich

Type 1	Medial head of gastrocnemius muscle is normal; popliteal artery is deviated medially and has an aberrant course
Type 2	Medial head of gastrocnemius muscle is located laterally popliteal artery has normal course
Type 3	An abnormal slip of mature skeletal muscle, fibrous band or additional tendinous band arising from migrating mesenchyme destined to become the medial head of gastrocnemius
Type 4	Popliteal artery is located deep in the popliteal fossa, entrapped by the popliteus muscle or a fibrous band
Type 5	Popliteal vein is also entrapped with any type of popliteal artery
Type 6	Popliteal artery is normally positioned and entrapped by a normally positioned often hypertrophic gastrocnemius muscle (functional entrapment)

Table 2. The incidence of the popliteal artery entrapment according to the type.

	Case (limbs)	Type 1 (%)	Type 2 (%)	Type 3 (%)	Type 4 (%)	Type 5 (%)	Type 6 (%)	Variant (%)
Kim (2006)[6]	14	0	43	36	0	7	14	-
Ozkan (2008)[7]	7	0	43	57	0	0	0	-
Hai (2008)[8]	11	36	45	18	0	0	0	-
Anil (2010)[9]	13	15	8	38	0	0	23	15
Zhong (2010)[10]	13	46	38	15	0	0	0	-
Rich (1979)[11]	14	43	7	14	28	0	0	7
Collins (1989)[12]	20	5	32	26	37	0	0	-
Levien (1999)[13]	88	5	14	37.5	9	0	34	-
Ringer (1999)[14]	16	6	25	6	31	6	12.5	-
Bustabad (2006)[15]	12	0	58	8	0	8	25	-

Table 3. Clinical symptoms of 22 patients with popliteal artery entrapment syndrome.

	n (%)
Symptoms	
Asymptomatic	2 (9.1%)
Unrelated to arterial ischemia	4 (18.2%)
Claudication	14 (63.6%)
Painful swelling	2 (9.1%)
Symptom duration	
Less than 2 weeks	1 (6.3%)
From 2weeks to 3 months	4 (25%)
More than 3 months	11 (68.8%)

n, number of patients

Table 4. Bilateral limb distribution of the popliteal artery entrapment syndrome.

Lt. \ Rt.	Normal (n=5)	PAES, total type (n=11)	PAES, partial type (n=6)
Normal (n=8)	0	5	3
PAES, total type (n=7)	3	4	0
PAES, partial type (n=7)	2	2	3

PAES, popliteal artery entrapment syndrome; n, number of limbs

Table 5. The stenosis degree of the popliteal artery according to the presence or absence of the popliteal artery entrapment syndrome and its types.

	Stenosis degree						
	0%	1-29%	30-49%	50-69%	70-89%	90-99%	100%
Normal (n=13)	12	0	1	0	0	0	0
PAES, total type (n=18)	0	1	0	2	1	1	13
PAES, partial type (n=13)	3	5	0	0	0	1	4

PAES, popliteal artery entrapment syndrome; n, number of limb

Table 6. The degree of medial displacement of the popliteal artery according to the presence or absence of the ppoliteal artery entrapment syndrome and its types.

Type	Normal	PAES, total type			PAES, partial type		
Significant popliteal artery stenosis		Overall	Yes	No	Overall	Yes	No
Number of limbs	13	18	17	1	13	5	8
Mean ± SD	79.8±11.0	20.5±10.0	20.3±8.9	24.9	57.4±22.4	39.1±23.3	68.8±12.4
Median (IQR)	75.5 (13.2)	20.2 (8.8)	21 (9.7)	NA	64 (34.7)	29 (16.9)	71.1 (14.5)

PAES,popliteal artery entrapment syndrome

SD, standard deviation

IQR, interquartile range

NA, not applicable

Significant or non-significant indicates stenosis of the popliteal artery.

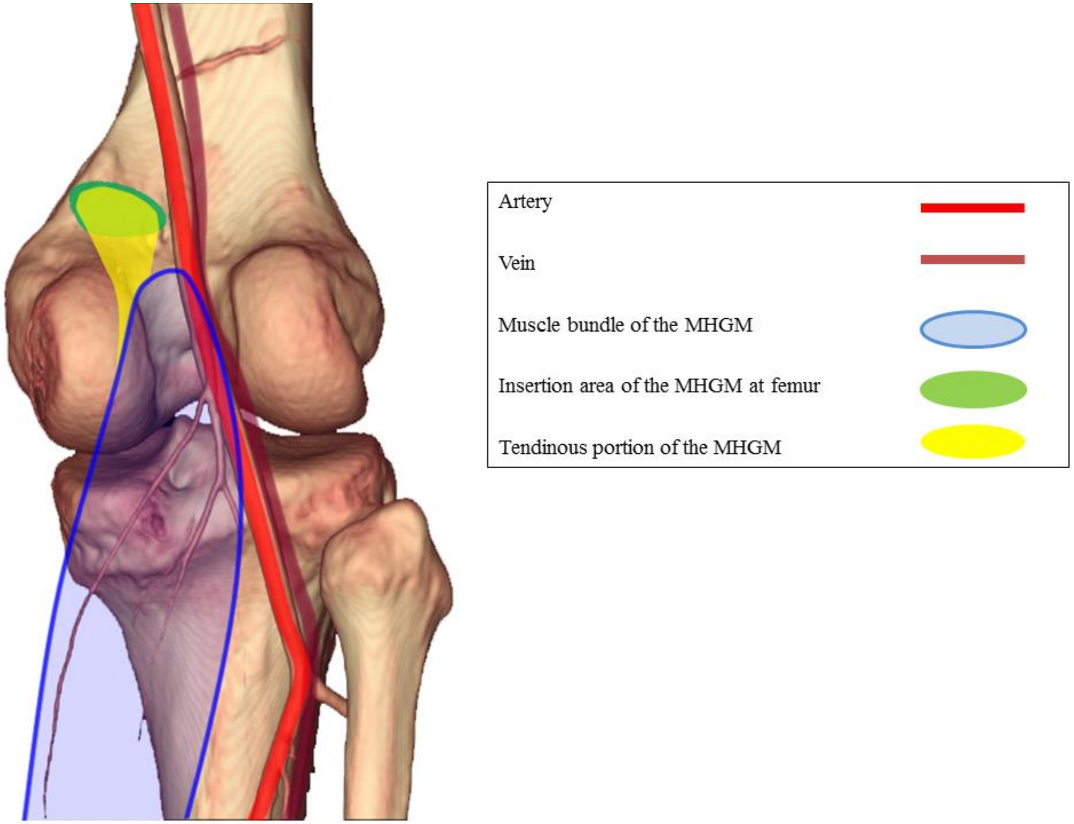
Table 7. Retrocondylar fat pad sign according to the presence or absence of the popliteal artery entrapment syndrome and its types..

Type	Normal (n=13)	PAES, total type (n=18)		PAES, partial type (n=13)		Overall PAES (n =31)	
Significant popliteal artery stenosis		Yes	No	Yes	No	Yes	No
Number of limbs	13	17	1	5	8	22	9
Present	0 (0%)	17 (100%)	1 (100%)	3 (60%)	2 (25%)	20 (91.0%)	3 (33.3%)
Absent	13 (100%)	0 (0%)	0 (0%)	2 (40%)	6 (75%)	2 (9.0%)	6 (66.7%)

PAES,popliteal artery entrapment syndrome

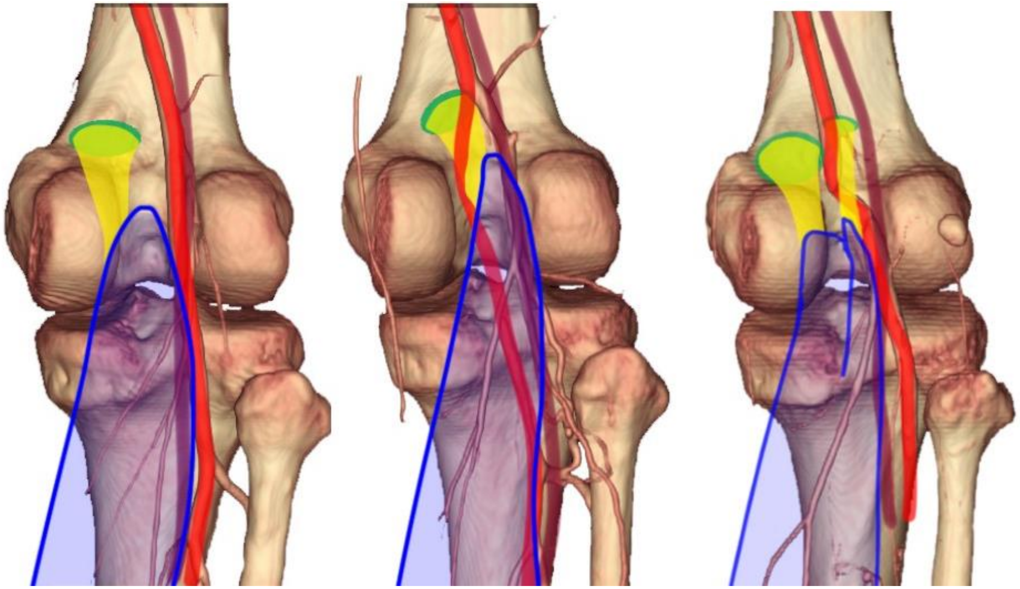
Significant or non-significant indicates stenosis of popliteal artery; n, number of li

Fig. 1. Schematic diagram of the normal anatomy at popliteal fossa, right limb.



(MHGM, medial head of gastrocnemius muscle)

Fig. 2. Type of popliteal artery entrapment syndrome.



(a) (b) (c)

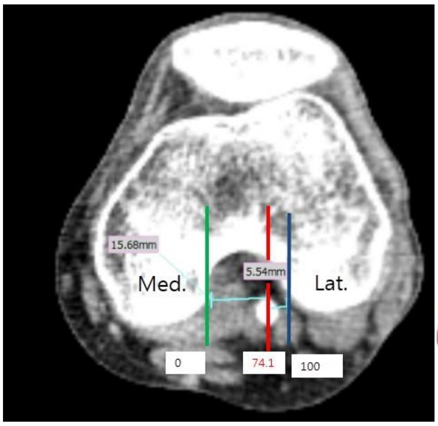
(a) Normal limb. The popliteal artery runs to the lateral aspect of the MHGM without displacement and lies in the lateral aspect of the intercondylar space.

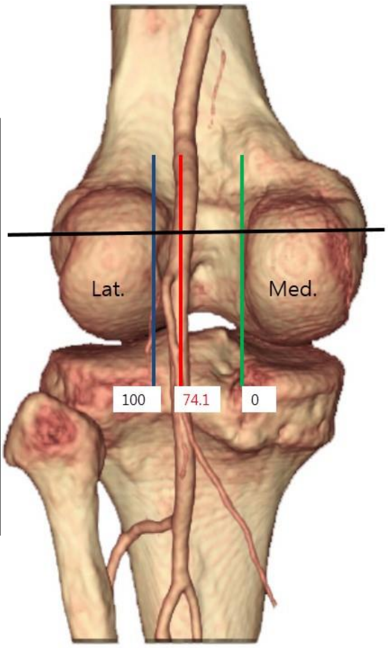
(b) Total type, defined as total anomalous insertion of the MHGM with medial displacement of the popliteal artery.

(c) Partial type, defined as partial anomalous insertion of the MHGM (as an accessory slip or fibrous band) and medial displacement of the popliteal artery.

(MHGM, medial head of the gastrocnemius muscle

Fig. 3. Measurement of the degree of medial displacement of the popliteal artery.



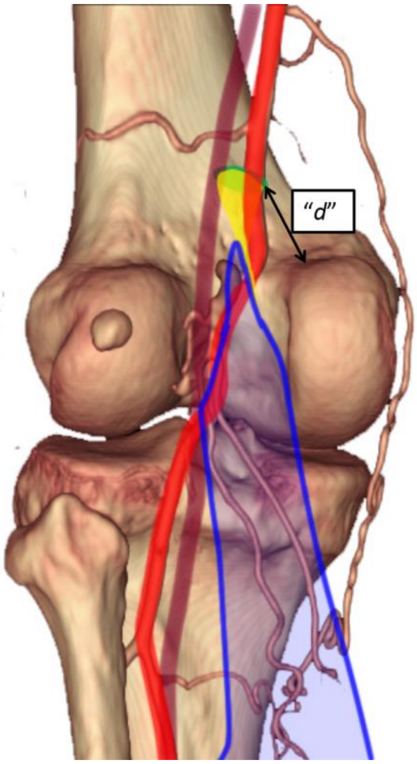


(a) (b)

The green line indicates the lateral border of the medial femoral condyle, the blue line indicates the medial border of the lateral femoral condyle, and the red line indicates the position of the popliteal artery on the axial CT scan (a) and the schematic diagram (b).

(Med.= medial femoral condyle, Lat=lateral femoral condyle)

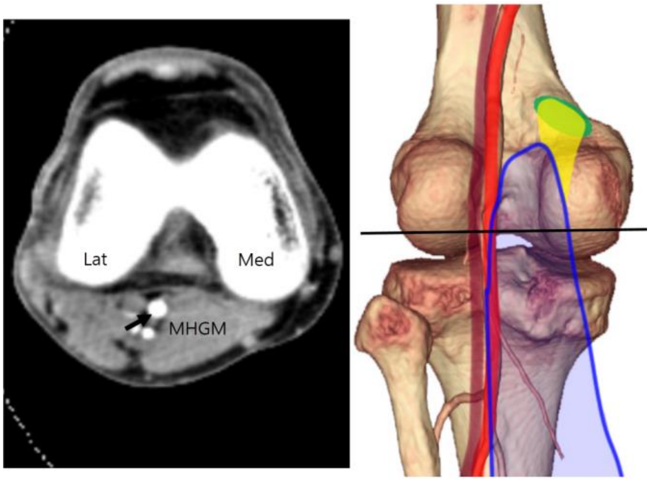
Fig. 4. Measurement of the distance between the medial head of the gastrocnemius muscle and the medial femoral condyle (MHGM-condyle distance).



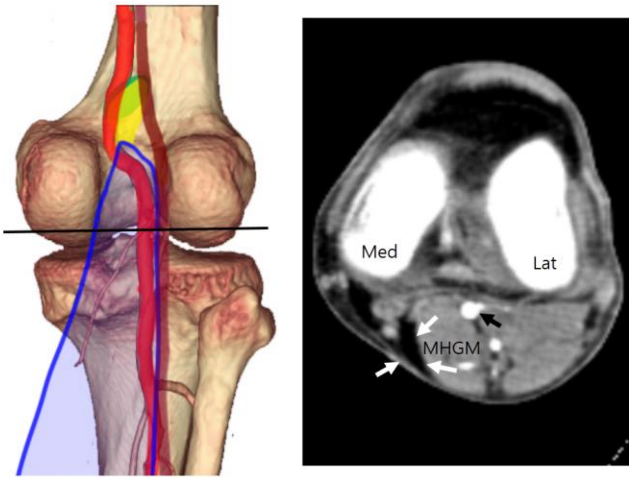
The "*d*" is the distance from the inferomedial border of femoral attachment of the MHGM muscle to the superolateral border of the medial femoral condyle.

(MHGM, medial head of gastrocnemius muscle)

Fig. 5. A 69-year-old male with a normal left limb (a) and a right limb with popliteal entrapment syndrome of the total type (b).



(a)



(b)

The axial CT scan of the left limb shows that it is full of muscles visualized in the medial compartment of the posterior knee. However, prominent fat (white arrow) was visualized in the medial compartment of the posterior knee in the right limb by a deviated MHGM.

(Med= medial femoral condyle, Lat=lateral femoral condyle, MHGM=medial head of gastrocnemius muscle, black arrow=popliteal artery)

Fig. 6. Attachment site of the medial head of gastrocnemius muscle at the femur.

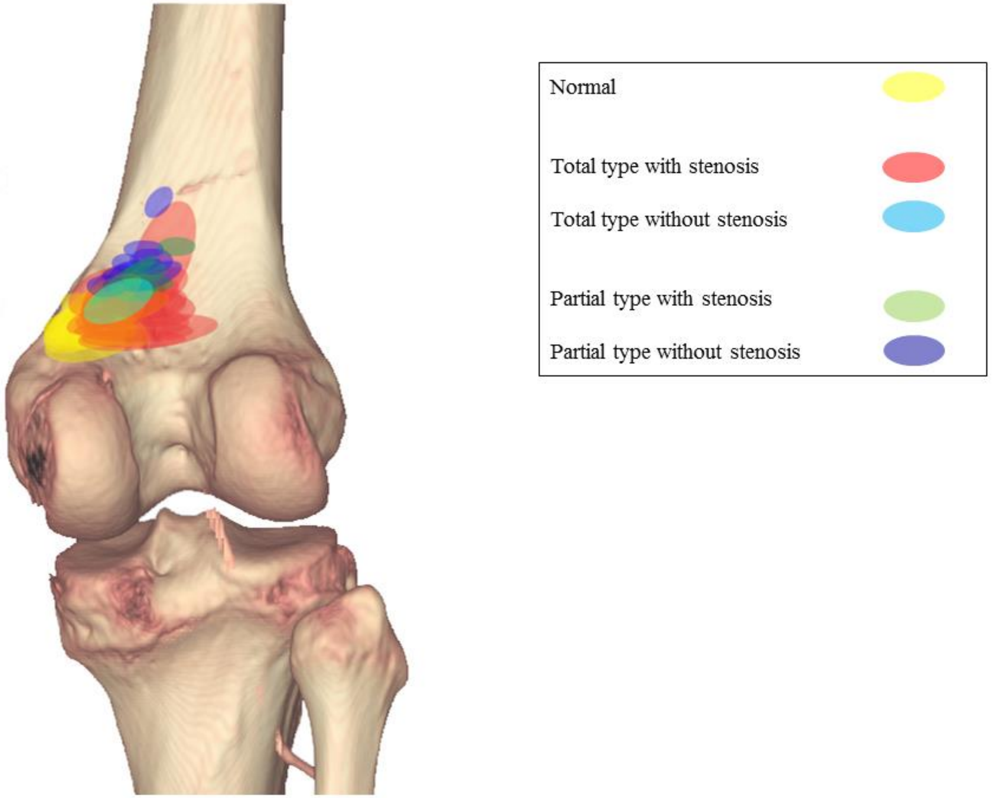
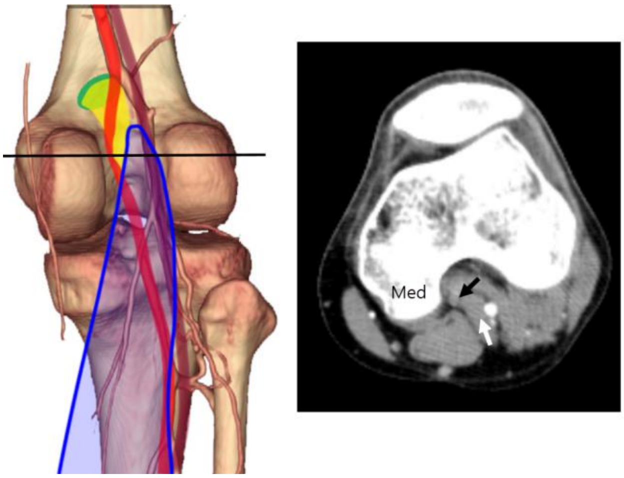
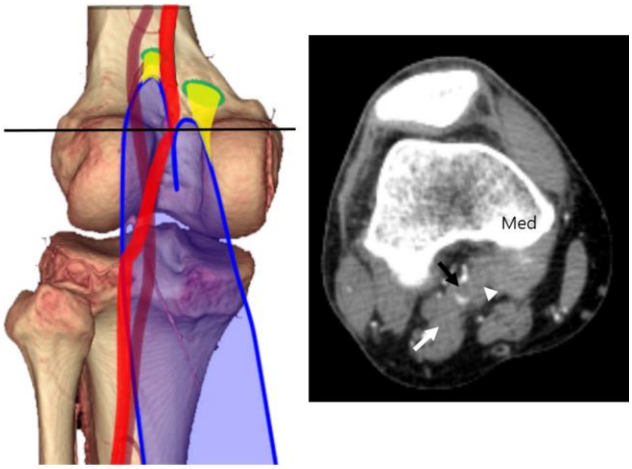


Fig. 7. The stenosis pattern of the popliteal artery.



(a)



(b)

(a) A 54-year-old male with PAES of the total type. The fibrous obliterated popliteal artery (black arrow) is seen between the medial condyle of the femur and the MHGM (white arrow).

(b) A 31-year-old male with PAES of the partial type. The popliteal artery (black arrow) is entrapped between the accessory muscle bundle (white arrow) of the MHGM and the major muscle bundle (white arrowhead) of the MHGM.

(Med= medial femoral condyle)

DISCUSSION

The popliteal artery is located behind the knee in the popliteal fossa and is a direct extension of the superficial femoral artery after it passes through the adductor hiatus, an opening in the tendinous slip of the great adductor muscle of the thigh. The popliteal artery lies posterior to the femur and anterior to the popliteal vein. The popliteal artery and vein are normally located between the two heads of the gastrocnemius muscle. Abnormalities in this relationship can produce PAES.

To our knowledge, this is the first study to evaluate 3D anatomical features of PAES in relation to the severity of arterial compromise. Using a 2D/3D interactive visualization technique, the morphology and attachment site of the MHGM and its anatomical relationship with popliteal vessels could be schematically drawn in all cases.

This study demonstrated that there was substantial overlap in the femoral attachment area of the MHGM between normal limbs and limbs with PAES. In addition, all popliteal arterial segments with stenosis had medial displacement due to an anomalous MHGM. Because of these reasons, it was difficult to discriminate between types 1 and 2 PAES according to the conventional classification described by Whelan and modified by Rich [17], [18]. In addition, it is not known whether discriminating between types 1 and 2 has any clinical implication on the treatment plan or severity of the disease. Therefore, we would like to propose a more simplified classification system for anomalous femoral attachment of the MHGM and medial malposition of the femoral artery causing PAES. In this study, we simply divided the anomaly into the total type and the partial type. The total type was defined as total anomalous insertion of the MHGM with medial malposition of the popliteal artery (corresponding to type 1 and type 2 of the classification of Whelan modified by Rich). The partial type was defined as partial anomalous insertion of the MHGM (as an accessory slip or fibrous band) and medial malposition of the popliteal artery (corresponding to type 3 of the classification of Whelan modified by Rich).

In this study, the type of PAES was a determining factor for significant popliteal artery stenosis, which suggests our simplified classification system is clinically relevant. The reason for the higher incidence of significant popliteal artery stenosis in the total type is the greater volume of anomalous MHGM and its closer attachment to the medial femoral condyle (demonstrated as the shorter MHGM-condyle distance in this study).

This study also suggested that the medial displacement of the popliteal artery, the distance from the inferomedial border of the MHGM attachment to the superolateral border of the medial condyle (MHGM-condyle distance), and the retrocondylar fat pad sign as 3D anatomical features correlated with popliteal artery stenosis. None of these features have ever been mentioned in previous research.

Among these features, the MHGM-condyle distance seems to be the most important and fundamental one. Because the MHGM-condyle distance reflects the width of the window for the popliteal artery to enter into the popliteal fossa in PAES, the smaller distance causes more severe medial angulation and entrapment of the popliteal artery. As expected, the MHGM-condyle distance was significantly associated with the medial displacement of the popliteal artery and the severity of popliteal artery stenosis.

The retrocondylar fat pad sign is the end result of the severe lateral displacement of the MHGM due to its anomalous femoral attachment. As expected, it was much more frequently found in the total type (17/18, 94.4%) than in the partial type (5/13, 38.5%). The retrocondylar fat pad sign and the medial displacement of the popliteal artery in the intercondylar space can be useful imaging features in the diagnosis of PAES and predicting the severity of popliteal artery stenosis.

Anomalous femoral attachment of the MHGM and medial malposition of the popliteal artery do not always cause significant popliteal artery stenosis, especially in the partial type. In this study, the vast majority of the total type (17/19, 94%) had significant popliteal artery stenosis. However, in the partial type, a minority of the patients (5/13, 38.5%) had significant popliteal artery stenosis. A possible explanation is the smaller volume of the accessory MHGM and its higher femoral attachment than in the total type.

There were several limitations in our study. First, because our study was retrospective, there may have been selection bias. Second, the statistical work-up was limited due to the small sample size and an insufficient number in a control group (i.e., limbs with PAES but no significant involvement of popliteal arteries). Third, despite excellent spatial resolution of MDCT, the evaluation for fine and thin structures is still limited, especially the tendinous portion of the muscle, and pathologic confirmation could not be performed. Fourth, we only evaluated the anatomic relationship between popliteal arteries and adjacent muscles, and excluded functional PAES. However, there is the possibility that anatomic PAES can be associated with functional factors, such as muscle hypertrophy affecting dynamic obstruction of popliteal arteries. The provocation study or quantitative measurement of the muscle volume was not performed in this study.

In conclusion, the severity of popliteal artery stenosis in PAES was affected by the anatomical features related to the anomalous insertion of the MHGM. More severe stenosis can be expected in the total type, with more medial displacement of the popliteal artery in the intercondylar space, shorter MHGM-condyle distance, and a positive retrocondylar fat pad sign.

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국문 초록

연구목표 : 슬와 동맥 포착 증후군에서 동맥 협착과 연관된 해부학의 3차원적 분석을 하고자 한다.

연구 재료 및 방법 : 후향적 연구방법으로 하지의 컴퓨터 단층촬영 혈관조영술을 시행하여 슬와 동맥 포착 증후군으로 진단된 22명의 환자(남:여 =21:1,평균나이=47.4 ± 19.9세,18~81세)를 대상으로 31개의 슬와동맥 포착 증후군이 있는 하지와 13개의 정상 하지를 분석하였다. 내측 비복근의 대퇴골 부착부위를 3차원적 분석 방법을 이용하여 분석하였고 내측 비복근과 슬와 동맥의 관계를 토대로 슬와 동맥 포착 증후군의 유형을 전체적 유형과 부분적 유형으로 분류하였다. 그 외 슬와 동맥의 협착 정도, 슬와 동맥의 내측 전위의 정도 및 슬와에서 내측 비복근의 대퇴골 부착부위까지의 거리 등을 분석하였으며 50%이상의 협착이 있는 경우 의미 있는 협착으로 간주하였다.

결과 : 22명의 환자 중, 편측 슬와 동맥 포착증후군은 13명(59.1%)에서, 양측 슬와 동맥 포착증후군은 9명(40.9%)에서 나타났다. 31개의 하지 중 전체적 유형은 18개(58.1%)였으며 부분적 유형은 13개(41.9%)였다. 슬와 동맥의 의미 있는 협착은 부분적 유형에서 38.5%, 전체적 유형에서 94%로 전체적 유형에서 더 빈번히 관찰되었다(p=0.0016). 또한, 슬와 동맥의 내측 전위 정도는 슬와 동맥의 협착 정도와 통계적으로 유의미한 상관관계를 가졌으며(스피어만 상관계수=−0.726, p<0.0001), 대퇴골의 내측 관절 융기의 상부 내측면으로부터 내측 비복근의 대퇴골 부위까지의 거리도 슬와 동맥의 협착 정도와 통계적으로 유의미한 상관관계를 지닌다(스피어만 상관계수=−

0.556,*p*=0.001). 전체적 유형이 부분적 유형에 비해 슬와 동맥의 내측 전위 가 심하였고(20.5 ± 10.0 vs. 57.4 ± 22.4, $p < 0.0001$), 슬와에서 내측 비복근의 대퇴골 부착부위까지의 거리가 짧았다 (13.1 ± 4.6 vs 22.9 ± 7.2, $p = 0.00038$). 관절융기 후방의 지방체의 존재는 의미 있는 협착이 있는 슬와 동맥 협착증후군에서 더 빈번히 나타났다(91.0% vs 33.3%, p=0.0024).

결론 : 컴퓨터 단층촬영의 영상을 사용한 포괄적인 3차원적 분석은 슬와 동맥 포착 증후군에서 해부학적 변이에 따른 의미 있는 동맥 협착의 상관관계를 파악하는데 유용하다. 특히, 전체적 유형, 큰 슬와 동맥의 내측 전위, 대퇴골의 내측 관절 융기의 상부 내측면으로부터 내측 비복근의 대퇴골 부위까지의 짧은 거리 및 관절융기 후방의 지방체의 존재는 의미 있는 협착을 동반한 슬와 동맥 포착 증후군을 시사하는 요인이 될 수 있다.

주요어 : 슬와 동맥 포착 증후군, 하지, 컴퓨터 단층촬영 혈관조영술

학번: 2009-21772

Appendix 1. Case Summery

Case	Sex/Age	Side	Type	Symptom	Symptom onset	Stenosis of popliteal artery (%)	Displacement of popliteal artery (medial=0, lateral=100)	Retrocondylar fat pad sign	Distance (mm)
1	M/18	Rt.	Partial	Claudication	6~7MA	100	29.0	Yes	15.0
		Lt.	Partial	No	-	10	43.2	No	22.0
2	M/32	Rt.	Partial	Claudication	2MA	90	19.4	Yes	17.0
		Lt.	Normal	No	-	0	72.1	No	-
3	M/52	Rt.	Total	Claudication	3MA	100	28.0	Yes	8.8
		Lt.	Normal	No	-	0	75.5	No	
4	M/51	Rt.	Total	Painful swelling	10DA	90	17.1	Yes	10.2
		Lt.	Normal	No	-	0	85.3	Yes	-
5	M/25	Rt.	Normal	No	-	0	86.2	Yes	-
		Lt.	Total	Unrelated	-	60	0	Yes	17.4
6	M/81	Rt.	Total	No	-	85	22.3	Yes	13.1
		Lt.	Partial	Unrelated	-	15	63.9	No	22.7
7	M/71	Rt.	Total	Claudication	2YA	100	11.1	Yes	7.2
		Lt.	Normal	No	-	45	71.7	No	-
8	M/69	Rt.	Total	Claudication	several YA	60	23.9	Yes	14.0
		Lt.	Normal	No	-	0	74.1	No	-

Distance : distance from the upper lateral border of medial femoral condyle to the medial border of medial head of gastrocnemius muscle attachment

Unrelated: symptoms unrelated to arterial ischemia

Appendix 1. Case Summery (continued)

Case	Sex/Age	Side	Type	Symptom	Symptom onset	Stenosis of popliteal artery (%)	Displacement of popliteal artery (medial=0, lateral=100)	Retrocondylar fat pad sign	Distance (mm)
9	M/30	Rt.	Normal	No	-	0	81.3	No	-
		Lt.	Total	Claudication	8YA	100	21.0	Yes	13.0
10	M/33	Rt.	Total	Claudication	2MA	100	6.3	Yes	17.0
		Lt.	Total	Claudication	3MA	100	11.2	Yes	15.0
11	M/72	Rt.	Partial	No	-	0	79.4	No	22.0
		Lt.	Partial	Unrelated	3YA	10	78.7	No	22.5
12	M/27	Rt.	Total	Claudication	2YA	100	20.2	Yes	10.0
		Lt.	Normal	No	-	0	70.4	No	-
13	M/61	Rt.	Total	No	-	100	23.3	Yes	13.0
		Lt.	Total	Unrelated	1MA	100	33.5	Yes	15.0
14	M/52	Rt.	Total	Claudication	several YA	100	25.6	Yes	24.0
		Lt.	Partial	No	-	10	78.5	Yes	43.0
15	M/22	Rt.	Total	Claudication	3YA	100	18.9	Yes	7.1
		Lt.	Total	Claudication	3YA	100	20.2	Yes	7.8
16	M/81	Rt.	Partial	No	-	0	65.3	Yes	14
		Lt.	Partial	No	-	0	64.1	No	22.8
17	M/65	Rt.	Partial	Claudication	20-30YA	100	26.2	No	10.1
		Lt.	Normal	No	-	0	82.8	No	-

Distance : distance from the upper lateral border of medial femoral condyle to the medial border of medial head of gastrocnemius muscle attachment

Unrelated: symptoms unrelated to arterial ischemia

Appendix 1. Case Summery (continued)

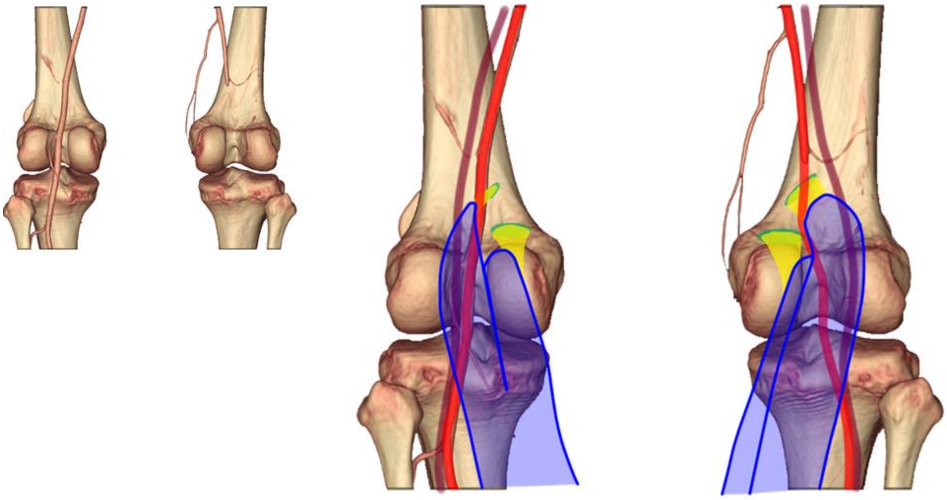
Case	Sex/Age	Side	Type	Symptom	Symptom onset	Stenosis of popliteal artery (%)	Displacement of popliteal artery (medial=0, lateral=100)	Retrocondylar fat pad sign	Distance (mm)
18	M/49	Rt.	Normal	No	-	0	63.5	No	-
		Lt.	Total	Claudication	3YA	100	28.6	Yes	10.6
19	M/54	Rt.	Total	No	-	15	24.9	Yes	15
		Lt.	Total	Claudication	3MA	100	13.7	Yes	15.7
20	M/31	Rt.	Normal	No	-	0	100	No	
		Lt.	Partial	Claudication	7MA	100	77.8	No	25.9
21	F/30	Rt.	Total	Claudication	6MA	100	24.6	Yes	9.6
		Lt.	Normal	No	-	0	74.7	No	-
22	M/37	Rt.	Normal	No	-	0	100	No	-
		Lt.	Partial	No	-	5	76.9	No	29.2

Distance : distance from the upper lateral border of medial femoral condyle to the medial border of medial head of gastrocnemius muscle attachment

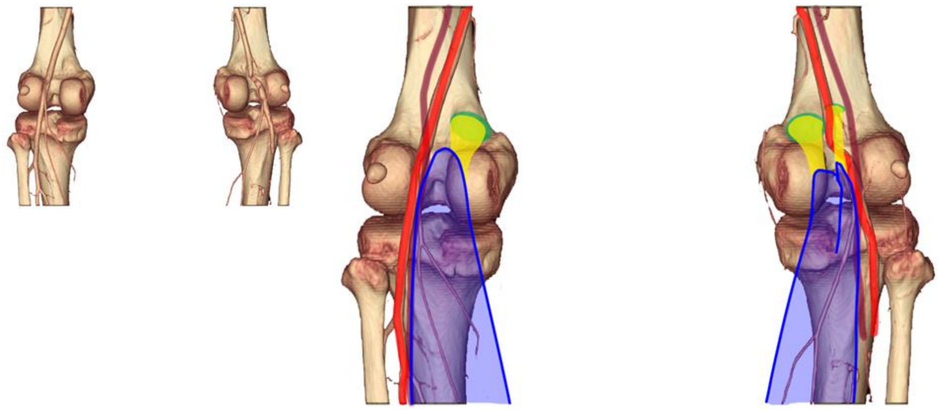
Unrelated: symptoms unrelated to arterial ischemia

Appendix 2. Schematic diaphragms of the case

Case 1

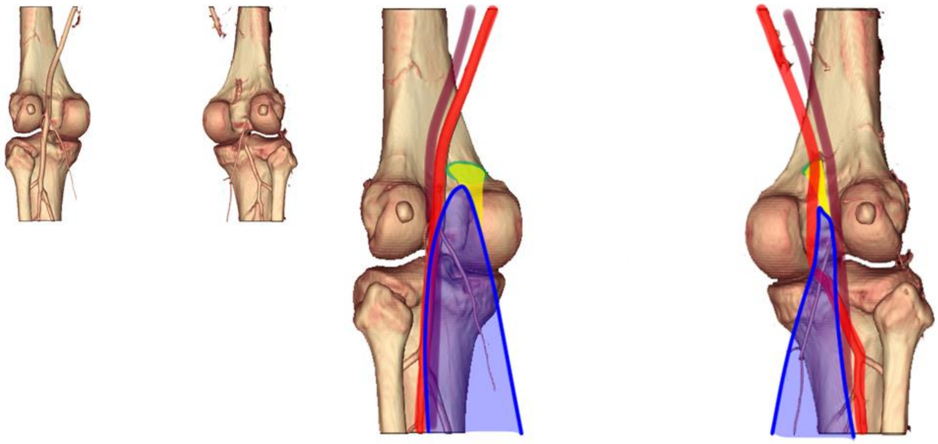


Case 2



Appendix 2. Schematic diaphragms of the case (continued)

Case 3



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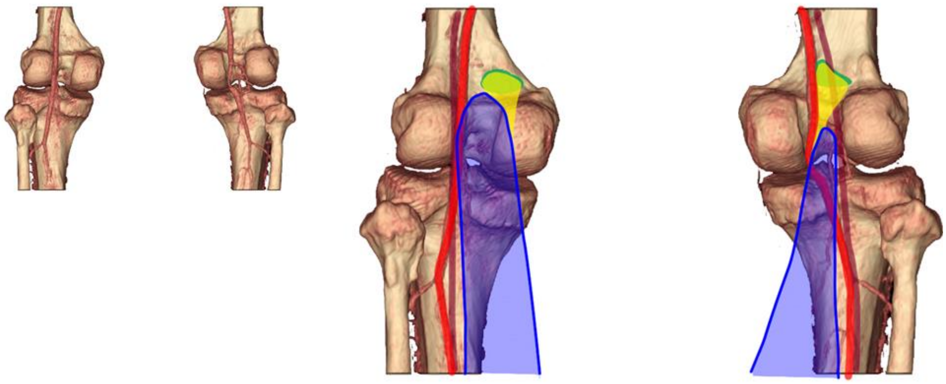
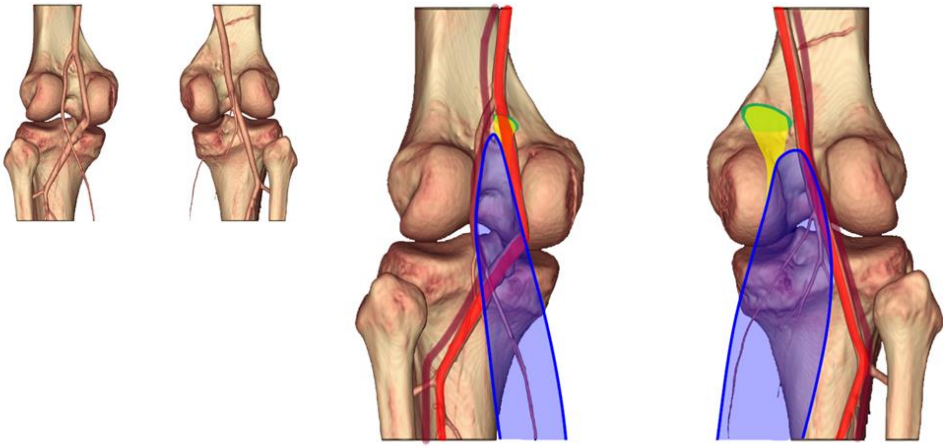


Appendix 2. Schematic diaphragms of the case (continued)

Case 5



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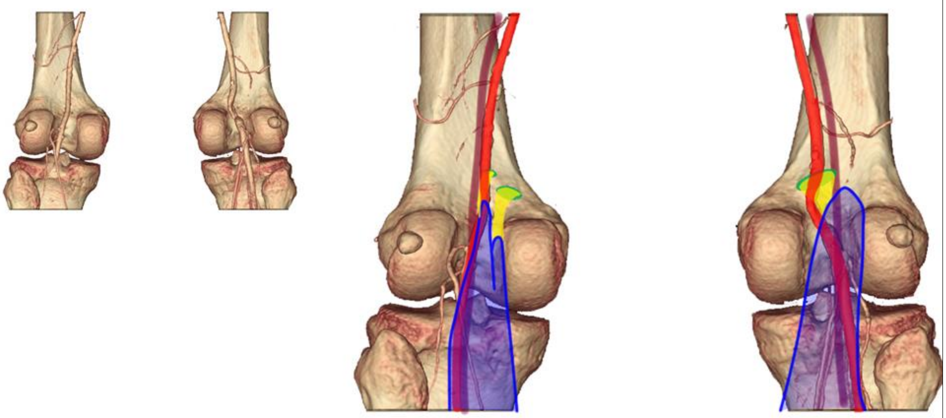
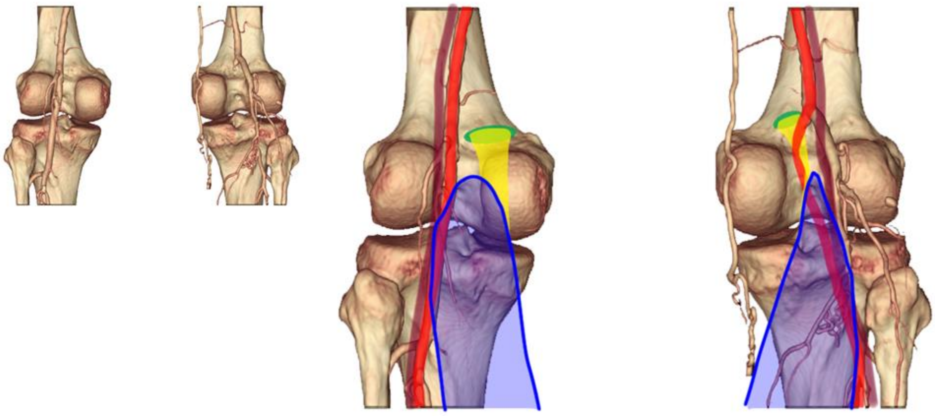
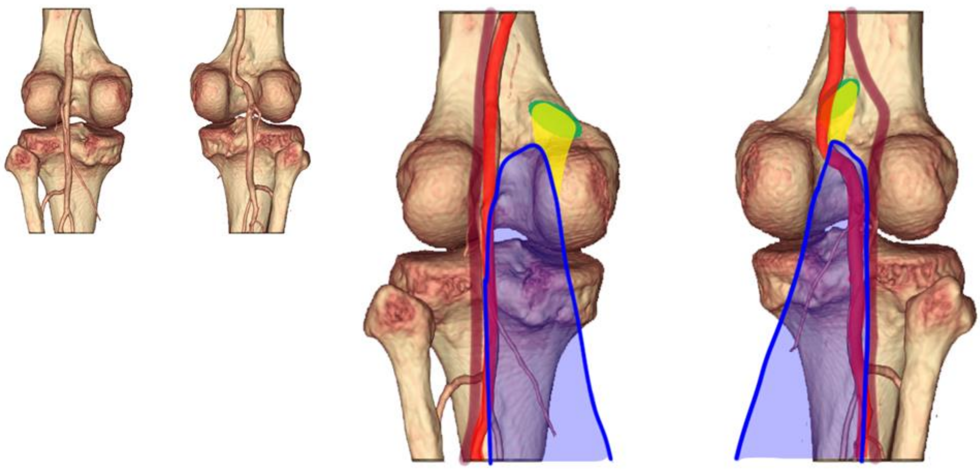


Appendix 2. Schematic diaphragms of the case (continued)

Case 7

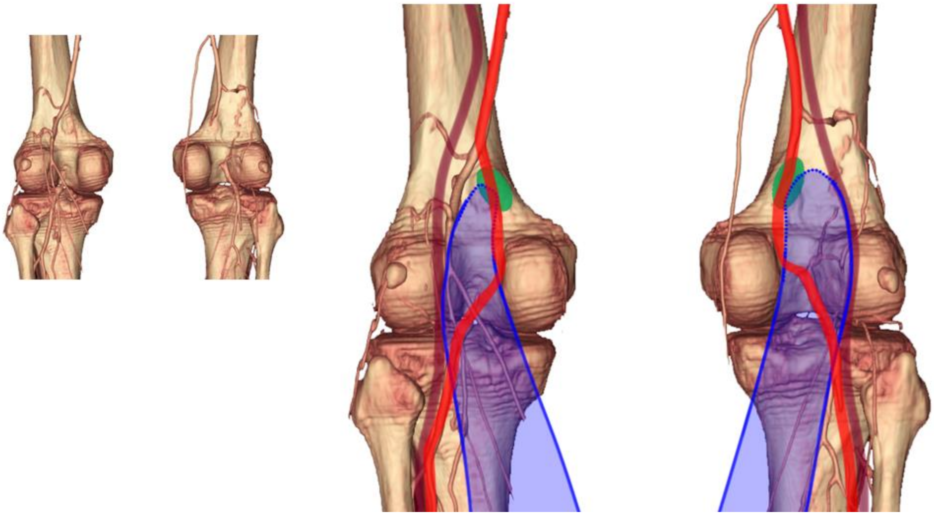


Case 8

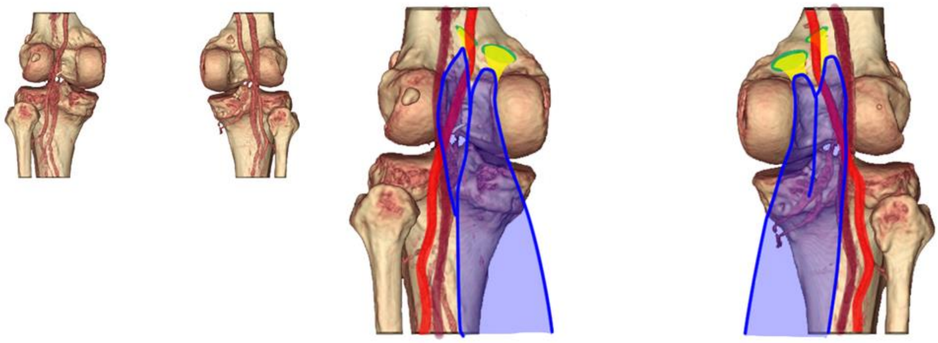


Appendix 2. Schematic diaphragms of the case (continued)

Case 10

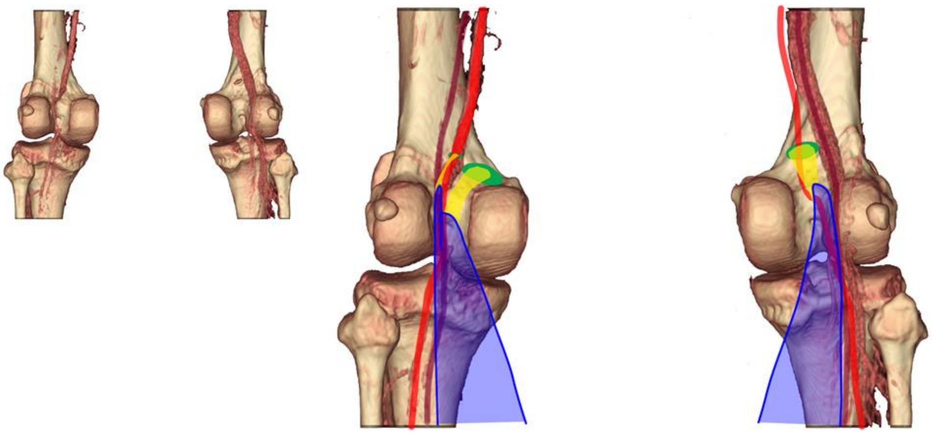


Case 11

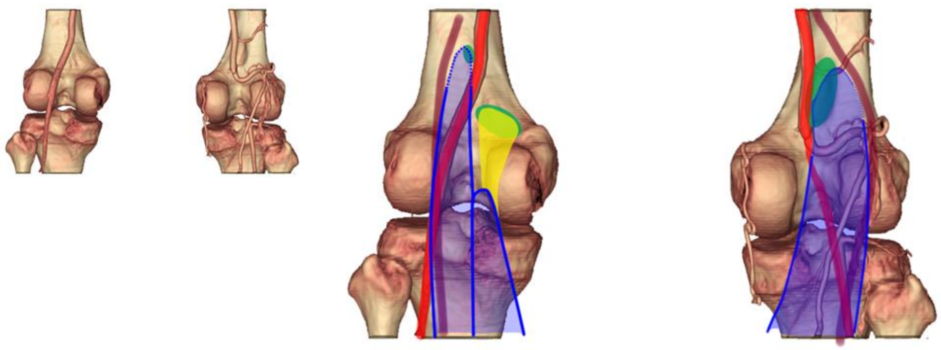


Appendix 2. Schematic diaphragms of the case (continued)

Case 13

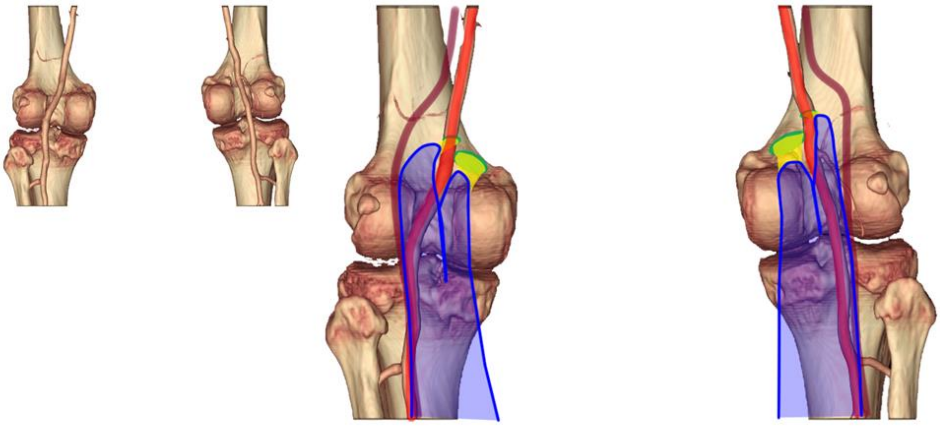


Case 14

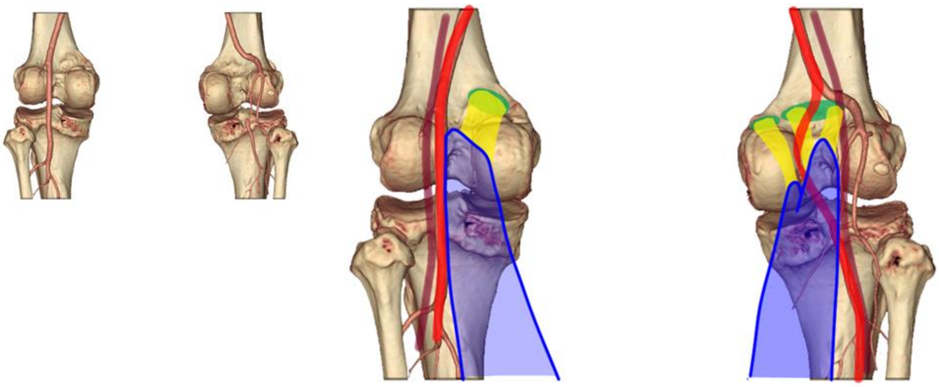


Appendix 2. Schematic diaphragms of the case (continued)

Case 16

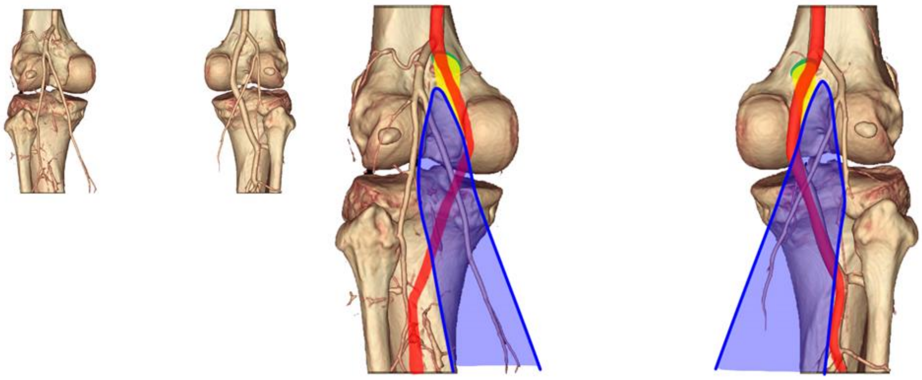


Case 17

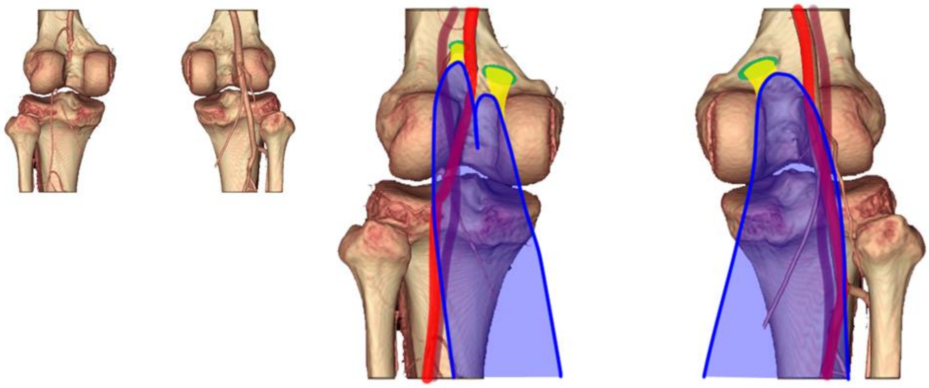


Appendix 2. Schematic diaphragms of the case (continued)

Case 19

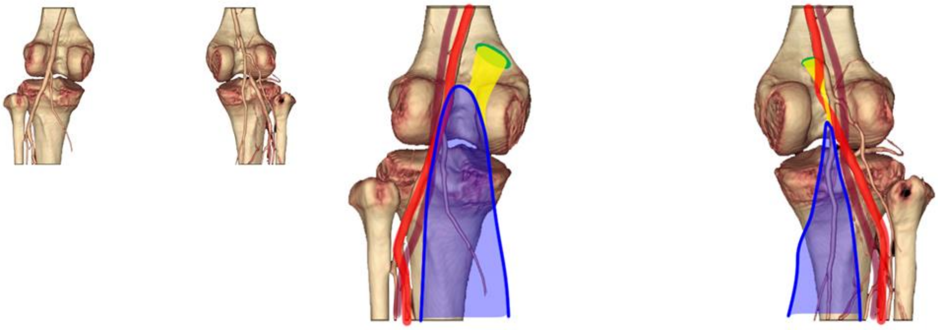


Case 20



Appendix 2. Schematic diaphragms of the case (continued)

Case 21



Case 22