VIA MEDICA

ORIGINAL ARTICLE

Folia Morphol.
Vol. 64, No. 4, pp. 315–320

ISSN 0015–5659
www.fm.viamedica.pl

External diameters of the crural arteries in patients with chronic critical limb ischaemia

Michał Szpinda

Department of Normal Anatomy, the Ludwik Rydygier Collegium Medicum in Bydgoszcz, the Nicolaus Copernicus University, Toruń, Poland

[Received 29 June 2005; Revised 7 September 2005; Accepted 16 September 2005]

Knowledge of the diameters of the crural arteries forms the basis for reconstructive vascular surgery and percutaneous angioplasty. The external diameters of the crural arteries were examined in 152 specimens of lower limbs by anatomical, digital and statistical methods. The diameters of all the crural arteries were significantly greater ($p \leq 0.01$) in the male subjects. The differences between the right and left arterial diameters were statistically significant ($p \leq 0.01$) only in relation to the posterior tibial artery. In subtypes IC and IIB the anterior tibial artery was the strongest, the peroneal artery was of intermediate diameter and the posterior tibial artery was the weakest. In subtype IB the anterior tibial artery presented as the predominant vessel but in subtypes IIA-1 and IIA-2 it was the posterior tibial artery that did so. In subtype IA 24 examples of the coexistence of angiometric variants of the crural arteries were distinguished. It was demonstrated that the strongest vessel was the anterior tibial artery (32.24%), rarely the posterior tibial artery (14.47%) or the peroneal artery (9.87%). In most cases (21.71%) three of the crural arteries had intermediate diameters. In 13.16% of cases there were two arteries of intermediate diameter, the posterior tibial and the peroneal, which accompanied a strong anterior tibial artery and, the least common variant (6.58%), two intermediate tibial arteries with a weak peroneal artery. A hyperplastic peroneal artery (6.59%) compensated for either the anterior tibial artery (1.98%) or the posterior tibial artery (4.61%).

Key words: infrapopliteal subtypes, external diameter, crural arteries, digital-image analysis, infrapopliteal angioplasty

INTRODUCTION

The crural segment is the most variable part of the arterial bed of the lower limbs [5]. In 21.7% of cases serious anomalies occur here [18]. The posterior tibial artery indicates the greatest variability, while the peroneal artery is the most stable [17]. A hyperplastic peroneal artery replaces the absent or hypoplastic tibial arteries [19]. Malformations of the lower limbs exist more frequently where the anterior tibial artery is absent [8] than when the posterior tibial artery is absent [7]. Knowledge of the diameters of the crural arteries forms the basis for reconstructive vascular surgery [2] and percutaneous angioplasty [1, 12]. The professional literature also contains arteriographic [3] and Doppler ultrasonographic [10, 11] data but no anatomical study of the crural arteries has yet been reported.

In view of the data available in the literature, the objective for the present research was to examine the original external diameters of the crural arteries in

Address for correspondence: Michał Szpinda, MD, Department of Normal Anatomy, the Ludwik Rydygier Collegium Medicum in Bydgoszcz, ul. Karłowicza 24, 85–092 Bydgoszcz, Poland, tel: +48 52 585 37 05, fax: +48 52 585 37 53, e-mail kizanat@cm.umk.pl

different subtypes of the popliteal artery division, taking into consideration gender and syntopic relations.

MATERIAL AND METHODS

The examinations were carried out on 152 specimens of lower limbs amputated at the thigh in 124 non-diabetic patients (95 men aged 41–96 years and 29 women aged 47–99 years) with chronic critical limb ischaemia in the course of atherosclerosis. The mean age of the male patients was 64.7 ± 9.8 years and that of the women was 69.4 ± 12.3 years, while the mean age of the whole series was 66.3 ± 9.2 years. After fixation by immersion with 10% formalin, the popliteal artery and its three branches (the anterior tibial, the posterior tibial and the peroneal arteries) were dissected using the anatomical method (Fig. 1). The configurations of the popliteal artery division (Fig. 2) were described according to the unified angiographic classification proposed by Lippert and Pabst [9] and Kim et al. [6]. Afterwards, the arterial pattern was analysed by the Digital Image Analysis System Q 500 MC of Leica (Cambridge), which evaluated external diameters [mm] [16]. The results obtained were statistically analysed by means of Student's t test for two mean independent variables (gender and syntopic differences) using the PC STAT 1.0 program.

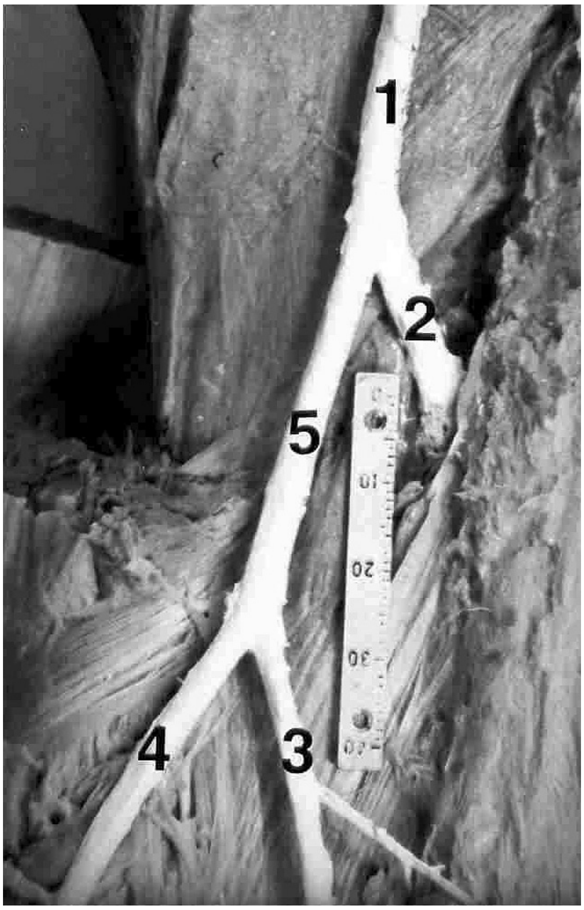

Figure 1. Usual system of popliteal artery division: 1 — popliteal artery, 2 — anterior tibial artery, 3 — peroneal artery, 4 — posterior tibial artery, 5 — posterior tibioperoneal trunk.

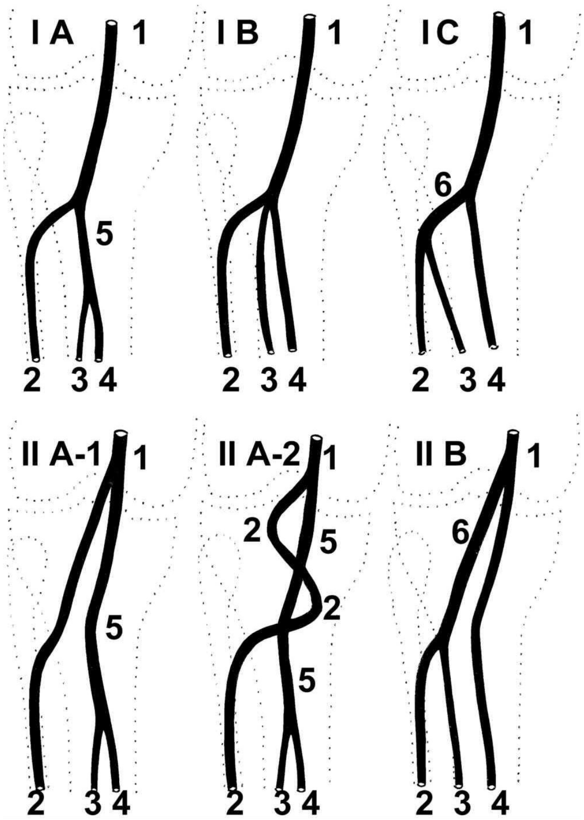

Figure 2. The unified angiographic classification of the popliteal artery division, proposed by Lippert and Kim: normal subtypes (IA–C) and high subtypes (IIA-1, IIA-2, IIB): 1 — popliteal artery, 2 — anterior tibial artery, 3 — peroneal artery, 4 — posterior tibial artery, 5 — posterior tibioperoneal trunk, 6 — anterior tibioperoneal trunk.

RESULTS

The mean values of the original diameters of the crural arteries in 6 subtypes of popliteal artery division are presented in Table 1 with gender and syntopic relations. The external diameters of the male subjects were significantly greater ($p \leq 0.01$) for all the crural arteries. The diameters of the right-sided arteries were consistently greater. The statistical analysis showed that the differences between right and left external diameters were statistically significant ($p \leq 0.01$) only in relation to the posterior tibial artery.

Table 1. The mean original external diameter of crural arteries ($\bar{x}$ ± SD)

Subtype of the popliteal artery	Frequency rate (%)	Original diameter values [mm]											
		Right						Left					
		Anterior tibial artery		Posterior tibial artery		Peroneal artery		Anterior tibial artery		Posterior tibial artery		Peroneal artery	
		Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
IA	87.5	3.52^{A} ± 0.31	3.47^{B} ± 0.33	$3.10^{A,C}$ ± 0.39	$3.03^{B,C}$ ± 0.37	2.71^{A} ± 0.27	2.65^{B} ± 0.27	3.48^{A} ± 0.31	3.40^{B} ± 0.32	$2.85^{A,D}$ ± 0.21	$2.48^{B,D}$ ± 0.22	2.65^{A} ± 0.27	2.61^{B} ± 0.23
IB	2.63	4.50^{A} ± 0.42	4.39^{B} ± 0.47	$3.45^{A,C}$ ± 0.33	$3.29^{B,C}$ ± 0.31	3.22^{A} ± 0.32	3.17^{B} ± 0.33	4.50^{A} ± 0.42	4.42^{B} ± 0.44	$3.36^{A,D}$ ± 0.35	$3.29^{B,D}$ ± 0.34	3.20^{A} ± 0.33	3.14^{B} ± 0.36
IC	1.97	4.10^{A} ± 0.41	4.02^{B} ± 0.40	$2.73^{A,C}$ ± 0.21	$2.67^{B,C}$ ± 0.27	2.85^{A} ± 0.24	2.75^{B} ± 0.26	4.05^{A} ± 0.46	3.97^{B} ± 0.35	$2.55^{A,D}$ ± 0.27	$2.45^{B,D}$ ± 0.27	2.80^{A} ± 0.21	2.74^{B} ± 0.29
IIA-1	1.32	2.35^{A} ± 0.23	2.29^{B} ± 0.21	$2.75^{A,C}$ ± 0.24	$2.61^{B,C}$ ± 0.24	2.27^{A} ± 0.21	2.12^{B} ± 0.29	2.05^{A} ± 0.28	1.98^{B} ± 0.22	$2.69^{A,D}$ ± 0.29	$2.59^{B,D}$ ± 0.28	2.25^{A} ± 0.24	2.20^{B} ± 0.21
IIA-2	0.66	2.20^{A} ± 0.24	2.15^{B} ± 0.22	$2.67^{A,C}$ ± 0.23	$2.65^{B,C}$ ± 0.20	2.15^{A} ± 0.26	2.09^{B} ± 0.26	2.20^{A} ± 0.24	2.12^{B} ± 0.29	$2.57^{A,D}$ ± 0.24	$2.48^{B,D}$ ± 0.25	2.07^{A} ± 0.29	1.17^{B} ± 0.25
IIB	5.92	4.05^{A} ± 0.41	3.97^{B} ± 0.34	$2.37^{A,C}$ ± 0.21	$2.30^{B,C}$ ± 0.20	3.15^{A} ± 0.32	3.12^{B} ± 0.31	4.17^{A} ± 0.41	4.10^{B} ± 0.41	$2.25^{A,D}$ ± 0.26	$2.20^{B,D}$ ± 0.22	3.18^{A} ± 0.31	3.12^{B} ± 0.36

Means (for sex — in rows) marked by the different letters: A and B differ significantly, $p \leq 0.01$; means (for side of body — in rows) marked by the different letters: C and D differ significantly, $p \leq 0.01$

In the arterial pattern with the anterior tibioperoneal trunks (IC, IIB) the anterior tibial artery was the strongest, the peroneal artery was classed as intermediate and the posterior tibial artery was the weakest. In the trifurcation of the popliteal artery (IB) the predominant vessel was the anterior tibial artery, whereas the peroneal artery displayed extensive variations at this point: in a quarter of cases it was stronger than the posterior tibial artery, in a quarter it was weaker and in half of cases it had the same diameter. Where there was a high division of the popliteal artery into the anterior tibial artery and the posterior tibioperoneal trunk (IIA-1, IIA-2) the posterior tibial artery was the predominant vessel.

The usual pattern of popliteal artery division (IA) presented great individual variability with respect to the original diameter. The strongest vessel (Table 2) was mainly the anterior tibial artery (32.24%), rarely (14.47%) the posterior tibial artery and the least common (9.87%) was the peroneal artery. Examination of the crural arteries was carried out, defining them as strong, intermediate and weak. Their diameters, large ($d \geq 4.0$ mm), intermediate (2.5 mm < < d < 4.0 mm) and small ($d \leq 2.5$ mm), were assumed as a criterion. With regard to the diameters of arteries in subtype IA, 24 variants were observed in which they coexisted (Table 3). In most cases (21.71%) the three crural arteries had comparable mean diameters within the intermediate diameter range (2.5–4.0 mm) while in 16.45% of cases their diameter values were identical. In 13.16% of cases equal-sized intermediate arteries coexisted, the posterior tibial and the peroneal, with the strong anterior tibial artery. Half as frequently (6.58%) the diameters of both tibial arteries were mutually comparable in their intermediate diameter with the weak peroneal artery. A configuration in which the mean diameter of the peroneal artery was accompanied by weak and intermediate tibial arteries occurred with a similar frequency (5.26%). In 4.61% of cases the strong anterior tibial artery and the intermediate posterior tibial artery coexisted, as often as the strong posterior

Table 2. Individual variability of external diameters of crural arteries in subtype IA

Arteries	Anterior tibial artery			Posterior tibial artery			Peroneal artery		
Diameter [mm]	Large ($d \geq 4.0$)	Intermediate ($2.5 < d < 4$)	Small ($d \leq 2.5$)	Large ($d \geq 4.0$)	Intermediate ($2.5 < d < 4$)	Small ($d \leq 2.5$)	Large ($d \geq 4.0$)	Intermediate ($2.5 < d < 4$)	Small ($d \leq 2.5$)
No.	49 (32.24%)	65 (42.76%)	19 (12.50%)	22 (14.47%)	85 (55.92%)	26 (17.11%)	15 (9.87%)	86 (56.58%)	32 (21.05%)

Table 3. Coexistence of crural arteries in respect to different external diameters in subtype IA

	Diameter of crural arteries	Strong anterior tibial artery and posterior tibial artery			Intermediate anterior tibial artery and posterior tibial artery			Weak anterior tibial artery and posterior tibial artery		
		Strong	Intermediate	Weak	Strong	Intermediate	Weak	Strong	Intermediate	Weak
peroneal	Strong	–	3 (1.97%)	6 (3.95%)	–	2 (1.32%)	1 (0.66%)	1 (0.66%)	1 (0.66%)	1 (0.66%)
	Intermediate	2 (1.32%)	20 (13.16%)	4 (2.63%)	7 (4.61%)	33 (21.71%)	8 (5.26%)	3 (1.97%)	8 (5.26%)	1 (0.66%)
	Weak	3 (1.97%)	7 (4.61%)	4 (2.63%)	3 (1.97%)	10 (6.58%)	1 (0.66%)	3 (1.97%)	1 (0.66%)	–

tibial artery with the intermediate anterior tibial and the peroneal arteries. Slightly less frequently (3.95%) the strong peroneal and the anterior tibial arteries were associated with the weak posterior tibial artery. The posterior tibial artery was hypoplastic in this pattern and terminated in the lower third part of the shin just below anastomosis with the peroneal artery. Its function was compensated for by a hyperplastic peroneal artery. Equally frequently (2.63%) a strong anterior tibial artery and weak posterior tibial artery were accompanied by an intermediate or weak peroneal artery.

Five variants, on the other hand, had an observed incidence of 1.97%. Three of these were represented by the combination of a weak peroneal artery and a strong posterior tibial artery with a strong, intermediate or weak anterior tibial artery. In combination with a strong anterior tibial artery there was a hypoplastic peroneal artery, which terminated in the middle third of the shin. A strong anterior tibial artery coexisted with a strong peroneal artery and an intermediate posterior tibial artery as frequently as did a strong posterior tibial artery with an intermediate peroneal artery and a weak anterior tibial artery.

The remaining 9 variants occurred very rarely: two of them in 1.32% of cases, these being intermediate tibial arteries with a strong peroneal artery and strong tibial arteries with an intermediate peroneal artery. The incidence of all the further 7 variants was 0.66%. Three of these were formed by a weak anterior tibial artery and a strong peroneal artery in association with strong, intermediate and weak posterior tibial arteries. In all these cases the anterior tibial artery was hypoplastic and terminated in the lower half of the shin. This artery was accompanied by a hyperplastic peroneal artery, the perforating branch of which compensated for the dorsal pedis artery. A further 4 variants, of identical frequency (0.66%), were formed by: 1) a strong hyperplastic peroneal artery, an intermediate anterior tibial artery and a hypoplastic posterior tibial artery, 2) an intermediate peroneal artery and weak tibial arteries, 3) and 4) a weak peroneal artery with weak and intermediate anterior and posterior tibial arteries. Consequently, both hypoplastic arteries, the anterior tibial and the peroneal, were observed in 1.98% of cases, whereas the posterior tibial artery was found in as many as 4.61%. A hyperplastic peroneal artery (6.59%) compensated for either the anterior tibial artery (1.98%) or the posterior tibial artery (4.61%). No two extreme angiometric configurations were identified in the research material, neither three strong nor three weak crural arteries. Similarly, there was no evidence for the coexistence of two strong posterior tibial and peroneal arteries with a weak anterior tibial artery.

DISCUSSION

The development and variability of the crural arteries depend on both the regression of the sciatic artery, which is the oldest axial trunk of the lower limb, and on the persistence of its junction with the primary femoral artery in the popliteal region. The popliteal, peroneal and anterior tibial arteries develop from the sciatic artery, whereas the posterior tibial artery is the vestige of the posterior branch of the saphenous artery [5, 6, 15, 17]. The crural segment is the most variable part of the arterial bed of the lower limbs.

Voboril [18] found that in as many as 21.7% of arterial anomalies were unilateral; in 4.6% of cases they were bilateral and in 2.3% bilaterally different anomalies were present. According to Voboril [18] and Piral et al. [13] the posterior tibial artery is the most variable crural vessel, the anterior tibial artery is of intermediate regularity and the peroneal artery is the most stable for both phylogenetic and embryological reasons. In the material used in this study variability of the crural arteries was distinguished in 19.09% of cases. These consisted of configuration variability (12.5%) and angiometric variability (6.59%) with hyperplastic and hypoplastic arteries. The results indicate that a high division of the popliteal artery is the only factor determining predominance of configuration variability of the posterior tibial artery, as the posterior tibial artery transfers its origin upwards in 5.92% (IIB) and the anterior tibial artery only in 1.98% of cases (IIA-1, IIA-2). The peroneal artery retains its constant position, but only joins the appropriate tibioperoneal trunk [17]. Evidence for the most frequent angiometric variability of the posterior tibial artery is its hypoplasia, identified in this study in 4.61% of cases, whereas hypoplasia of both the anterior tibial artery and the peroneal artery occurred less frequently, in 1.98% of cases each.

Some studies have shown an association between an abnormal arterial pattern and bony malformations of the lower limb. Kitziger and Willkins [7] also describe the absence of the posterior tibial artery in a 3-month-old child with the *talipes equinovarus* deformity. Zwass and Abdelwahab [19] presented a rare developmental anomaly of absence of the posterior tibial artery and hypoplastic anterior tibial artery. In this case a marked hyperplastic peroneal artery compensated for the absent arteries. The peroneal artery also gave collaterals to form the dorsal pedis and the plantar arteries. Zwierzchowski et al. [20] observed hypoplastic anterior and posterior tibial arteries combined with fibular aplasia, anterior bowing of the tibia, and congenital pseudoarthrosis. Hootnick et al. [4] and Levinsohn et al. [8] have also shown an association between an absence of the anterior tibial artery and bony malformations of the human lower limbs (clubfoot, deficiency of the calf bone, tibial aplasia, metatarsal absence, ectrodactyly and diplopodia). In limbs that contain the remnant of a missing structure, it is concluded that injury occurred after the mesenchyme was instructed to form that structure and these abnormalities are termed "post-specification" defects. In circumstances in which limb duplication occurs the injury affected the signal before the instruction of the mesenchyme to develop into a specific structure was completed and these abnormalities are termed "pre-specification" malformations. The authors hypothesise that the abnormal arterial pattern put the limb at risk of teratogenic damage by reducing the number of collateral blood supply routes. Rodriguez [14] described the coexistence of the campomelic syndrome with the absence or marked deficiency of the anterior tibial artery. My results have not shown the absent posterior tibial artery but only its hypoplasia (4.61%), which, in common with the anterior tibial hypoplasia (1.98%), was compensated for by a hyperplastic peroneal artery, coexisting here in 6.59% of instances.

In this study the original diameters of the male subjects were significantly larger for the three calf arteries, constituting gender differences. The results present significant syntopic differences concerning the diameter of the posterior tibial artery, which was larger on the right side. These observations agree closely with the results obtained by Macchi et al. [11]. This author observed with the use of Doppler ultrasonography that the diameters of the right crural arteries were consequently larger than the ones in the left arteries, but the differences were statistically significant only in relation to the posterior tibial artery in males. Compared to those of the females, the arterial calibres of the male subjects were significantly larger ($p < 0.01$) for all arteries. In both sexes there was a statistically significant direct relationship between vessel calibre and age. There was no correlation between arterial diameters and body index. External diameters of the calf arteries presented in this work were much larger than the mean diameters in the angiographic material of Heise et al. [3]: 0.34 ± 0.03 mm for the posterior tibial artery, 0.27 ± 0.02 mm for the anterior tibial artery and 0.26 ± 0.21 mm for the peroneal artery. The differences between the data of Heise et al. [3] and my observations resulted from the fact that the subject of the former study was not the external but the internal diameters of arteries with severe pathological changes.

The diameter and the number of patent crural arteries are the most important determinants of the patency rate in femoropopliteal and femorotibial grafts [2]. With three patent crural arteries the cumulative patency rate amounted to 82.2%, whereas with only a single patent artery it decreased to 56% ($p \leq 0.01$). Advances in radiological techniques have allowed arterial stenoses situated in the distal arterial tree to be successfully treated. The application of Schneider's balloon [1], 2 cm long and 2.5–3 mm in diameter, enables subintimal distal crural artery dilatations to be performed in 84% of instances. In the patients of Nydahl et al. [12] 89% of angioplasty procedures were applied to the following: a single calf vessel (the anterior tibial artery — 21.4%, the peroneal artery — 24.9% and the tibioperoneal trunk in 17.8%), two calf vessels —17.3% and three calf vessels — 3.7%. Subintimal (in long occlusion) or transluminal (in short occlusion) percutaneous angioplasty in patients with infrapopliteal artery occlusion and critical ischaemia is safe, effective, and offers a low-risk alternative to distal reconstructive surgery.

REFERENCES

1. Bolia A, Sayers RD, Thompson MM, Bell PR (1994) Subintimal and intraluminal recanalisation of occluded crural arteries by percutaneous balloon angioplasty. Euro J Vasc Surg, 8: 214–219.
2. Gruss JD, Hiemer W (1992) Results of femoropopliteal and femorotibial greater saphenous vein in situ bypass. Life table analysis. Int Angiol, 11: 94–105.
3. Heise M, Kruger U, Ruckert R, Rad F, Scholz H, Neuhaus P, Settmacher U (2003) Correlation between angiographic runoff and intraoperative hydraulic impedance with regard to graft patency. Ann Vasc Surg, 17: 509–515.
4. Hootnick DR, Packard DS, Levinsohn EM, Lebowitz MR, Lubicky JP (1984) The anatomy of a congenitally short limb with clubfoot and ectrodactyly. Teratology, 29: 155–164.
5. Kim M, Dupuy JP, Dany F (1981) Embryology, anomalies, dystrophy and pathology of the lower limbs arteries (author's transl). J Mal Vasc, 6: 187–192.
6. Kim D, Orron DE, Skillman JJ (1989) Surgical significance of popliteal arterial variants. A unified angiographic classification. Ann Surg, 210: 776–781.
7. Kitziger K, Willkins K (1991) Absent posterior tibial artery in infant with talipes equinovarus. J Pediatr Orthop, 11: 777–778.
8. Levinsohn EM, Hootnick DR, Packard DS (1991) Consistent arterial abnormalities associated with a variety of congenital malformations of the human lower limb. Invest Radiol, 26: 364–373.
9. Lippert H, Pabst R (1985) Arterial variations in man: classification and frequency. JF Bergman Verlag, Munich, pp. 60–64.
10. Macchi C, Giannelli F, Catini C, Gulisano M, Pacini P, Brizzi E (1994) The original caliber of the lower limbs arteries as possible risk factor for complications of atherosclerosis: a statistical investigation in 90 subjects by echocolor-doppler. Ital J Anat Embryol, 99: 219–228.
11. Macchi C, Gulisano M, Giannelli F, Catini C, Pacini P, Brizzi E (1994) The calibre of the common femoral, popliteal, and posterior tibialis arteries: a statistical investigation in 100 healthy subjects by color Doppler ultrasonography. Ital J Anat Embryol, 99: 157–169.
12. Nydahl S, Hartshorne T, Bell PRF, Bolia A, London NJM (1997) Subintimal angioplasty of infrapopliteal occlusions in critically ischaemic limbs. Eur J Endovasc Surg, 14: 212–216.
13. Piral T, Germain M, Princ G (1996) Absence of the posterior tibial artery: implications for free transplants of the fibula. Surg Radiol Anat 18: 155–158.
14. Rodriguez JI.1993. Vascular anomalies in campomelic syndrome. Am J Med Genet, 46: 185–192.
15. Savov JD, Wassilev WA (2000) Bilateral persistent complete sciatic artery. Clin Anat, 13: 456–460.
16. Szpinda M, Flisiński P, Molski S (1999) Anatomical and clinical aspects of collateral knee circulation in patients with chronic lower limb ischemia. Med Sci Monit, 5: 25–31.
17. Szpinda M (2005) Angiographic study of the tibioperoneal trunks in patients with aorto-iliac occlusive disease. Ann Anat, 187: 405–410.
18. Voboril R (1990) Note on variability of the arteries of the lower extremities in man. Folia Morphol (Praha), 38: 256–272.
19. Zwass A, Abdelwahab IF (1986) A case report of anomalous branching of the popliteal artery. Angiology, 37: 132–135.
20. Zwierzchowski H, Garncarek P, Judycki A (1990) Vascularization in congenital hypoplasia of the leg in children. Chir Narzadow Ruchu Ortop Pol, 55: 469–476.