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ARTICLE

Anatomic study of septocutaneous system of the human fetuses' lower leg: peroneal artery

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ABSTRACT

The septocutaneous system of the lower leg perforating blood vessels consists of a vascular basis of fasciocutaneous flaps. This system is of particular importance when designing distally based fasciocutaneous flaps that are the 'workhorse' in reconstructing the distal third of the lower leg and foot. The aim of this study was to provide a comprehensive, clear and conclusive overview of the lower-leg septocutaneous system of skin blood supply in fetal age. Dissection was conducted on 20 fetuses of both sexes and gestational age from 20 to 28 weeks. The focus was on the vascular anatomy of peroneal artery and its septocutaneous (fasciocutaneous) perforating arterial vessels. Cluster analysis was applied to the obtained data. A total of 212 perforating arterial vessels were identified for peroneal artery. The average number of perforating arterial vessels was 5.32 (ranging from 4 to 7). Based on cluster analysis, perforating blood vessels were more likely to be found at certain lower-leg levels ('safe levels of finding perforators'). The presence of septocutaneous system of perforating blood vessels and reliability of their localization even in the fetal period allows for the application of these findings in the lower leg reconstructions in children of early age.

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Introduction

Discovery of fasciocutaneous blood vessels system of the lower leg resulted in significantly more profound understanding of skin vascularization [1]. Consequently, the main arteries of the body have been re-examined with an emphasis on the perforating branches that provide direct skin vascularization. The flaps, which are based on the blood vessels passing through the duplication of the septum in the lower leg, and consisting of skin, subcutaneous fat and deep fascia, are called fasciocutaneous flaps [2]. Although three main classifications of fasciocutaneous flaps have been described to date, they can be simply divided based on the course of the vessel penetrating the deep fascia into direct or indirect flaps [3]. The initial period of advancements in this area was followed by a period when numerous studies on this blood vessels system were conducted. This period was marked by two distinct pathways: solving disagreements and confusion in the nomenclature and names of the new concepts of perforator flaps, on one hand, and further exploration and understanding of this new concept on the other [4].

From a practitioner's point of view, the discovery of this type of flap is particularly important for the treatment of the lower leg defects due to its structural characteristics and the lack of reliable flap locations [5]. Furthermore, patient studies have shown that flaps are a significantly better choice compared to skin grafts when it comes to lower leg reconstruction [6]. The greatest advantages are the simplicity of the procedure, very high success rate, and relatively small number of minor disadvantages [7]. Besides, the procedure can be applied to wounds with different origins (e.g. fourth-degree burn injuries [7], blast and high-velocity projectile wounds [8] and distal tibial fracture [9]) and injuries of various size, location and depth [5].

Numerous anatomical studies on cadavers have been carried out in order to determine the localization of perforating blood vessels of the main lower-leg arterial trunks and the results, although often significantly different, were of great help in planning and designing the distally based flaps of the lower leg ('separated as septocutaneous perforators of the lower leg'). However, studies on fetuses that would shed some light on the vascular anatomy of this system of blood vessels are very rare and often inconclusive, despite the fact that pediatric cases are more complicated [10] and require further theoretical knowledge. This research is, therefore, an attempt to provide a comprehensive, clear and conclusive overview of the lower-leg septocutaneous system of skin blood supply in fetal age. The results were statistically analyzed in order to enable comparison with other studies of this kind. Implications of this article go beyond contribution to the theoretical knowledge, as the information provided can be applied to cases of lower leg reconstruction in children.

Materials and methods

The study was conducted on 40 lower extremities from 20 human fetuses. The fetuses were prepared by fixation in 10% formalin and their blood vessels were injected with Micropaque solution (barium sulfate) (Merck, Darmstadt, Germany). Fetuses were collected in the Department of Anatomy between 1962 and 1985. All fetuses were medico-legally obtained from the Clinic of Gynecology and Obstetrics of the Faculty of Medicine in Nis, Serbia. No anatomical deformities or systematic diseases were

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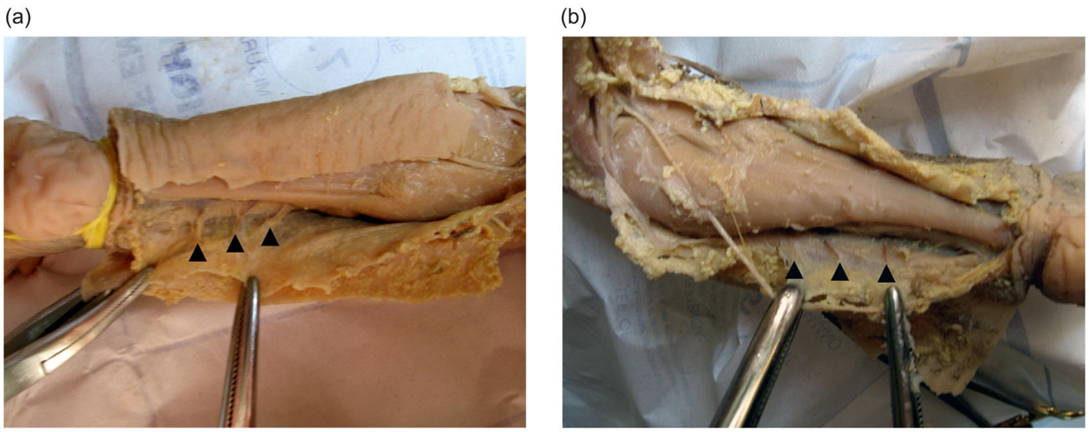

Figure 1. (a, b) Peroneal artery perforators (fetal dissections without contrast).

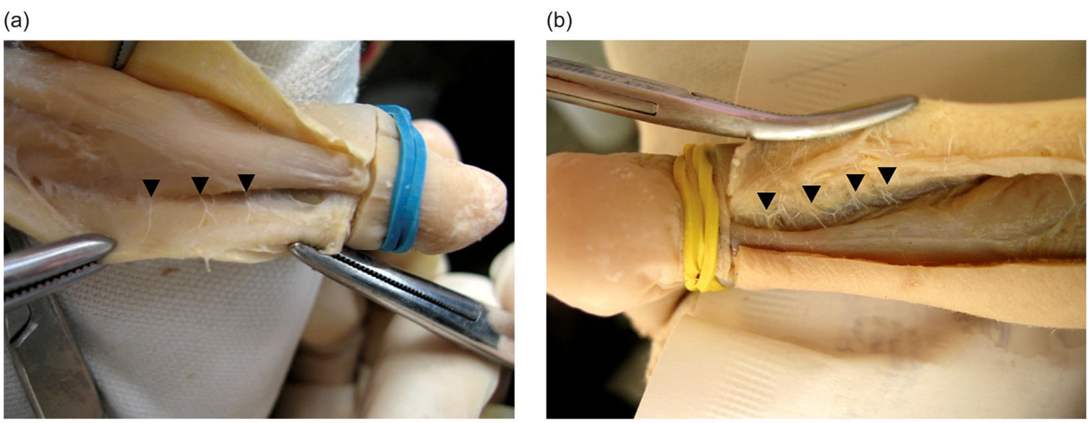

Figure 2. (a, b) Peroneal septocutaneous perforators (with contrast injected) from their origin to the deep fascia.

recorded. The research was conducted according to the Ethical Guidelines of the 1975 Helsinki Declaration and approved by the Ethics Committee of the Faculty of Medicine, University of Niš, Niš, Serbia.

Fetal age ranged from the third to the ninth lunar month and was established by measuring crown-rump length. Microdissection of the fetal lower extremities was performed under ×5 magnifying lenses. Two horizontal cuts and one vertical cut of the skin were made. The first horizontal cut was made at the level of the popliteal fold and the second was made at the level of the medial and lateral malleolus. The vertical cut extended from the middle of the upper horizontal cut at the level of the popliteal fold to the middle of the lower horizontal cut. After that, the dissection was going through the skin, subcutaneous tissue and fascia, and then continued carefully medially and laterally until reaching medial and lateral septum of the lower leg. Afterwards, the origin of arterial septocutaneous vessels from posterior tibial and peroneal arteries was noted and the distance from lower horizontal cut to the origin of perforating vessels was clearly measured. Characteristic cases were photographed.

Cluster analysis was conducted on the raw data obtained from the primary research. Portable IBM SPSS Statistics v19 (Armonk, NY) was used and *K*-means cluster analysis was conducted. Due to the small data set, the number of iterations was set at 10 in order to determine whether it is possible to run this type of analysis. SPSS (SPSS Inc., Chicago, IL) conducted the command without any further notifications, meaning that the data set is large enough. The number of clusters was set at three and clusters were divided based on the number of perforators found in each area of fetuses' lower leg. Clusters were divided into low, medium and high-density area. Additionally, cluster membership information was saved.

Results

Anatomical microdissection of fetal lower legs (as shown in Figure 1(a,b)) with or without contrast injected (shown in Figure 2(a,b)) was used in order to define the number of septocutaneous perforator vessels and their localization.

Peroneal septocutaneous perforating vessels erupted from posterior intermuscular septum of the lower leg, proximally between *m. soleus* and *m. peroneus brevis*, distally in a layer between *m. flexor hallucis longus* and *m. peroneus brevis*. In 11 fresh cadaveric dissections of the lower legs, it was found that the number of septocutaneous perforating vessels of peroneal artery amounted to 4, in 23 dissections their number was 5, while in six dissections peroneal artery separated the six septocutaneous perforating vessels, with an average value of 4.87 ± 0.65 (total 195 perforators).

In order to statistically process the data, conduct the subsequent analysis and enable comparability of the results obtained by our research and the results of other similar studies, fetal lower legs were 'divided' in 10 equal parts (the most distal segment is marked as the first). Levels at which perforating blood vessels are encountered as well as outbreak schedule of perforating vessels of peroneal artery, obtained by dissection of the fetuses, are shown in Table 1 and Figure 3.

Table 1. Number (and percentage) of fetuses with septocutaneous perforating vessels of peroneal artery and percentage of them in every group.

1/10 length of the lower leg (intermalleolar line – popliteal crease)	Number of dissections where perforators were found	Percentage of the total number of dissections (%)	Percentage of the total number of perforators (%)
First	6	15	3.07
Second	17	42.5	8.71
Third	32	80	16.41
Fourth	31	77.5	15.89
Fifth	24	60	12.3
Sixth	30	75	15.38
Seventh	23	57.5	11.79
Eighth	16	40	8.2
Ninth	10	25	5.12
Tenth	6	15	3.07

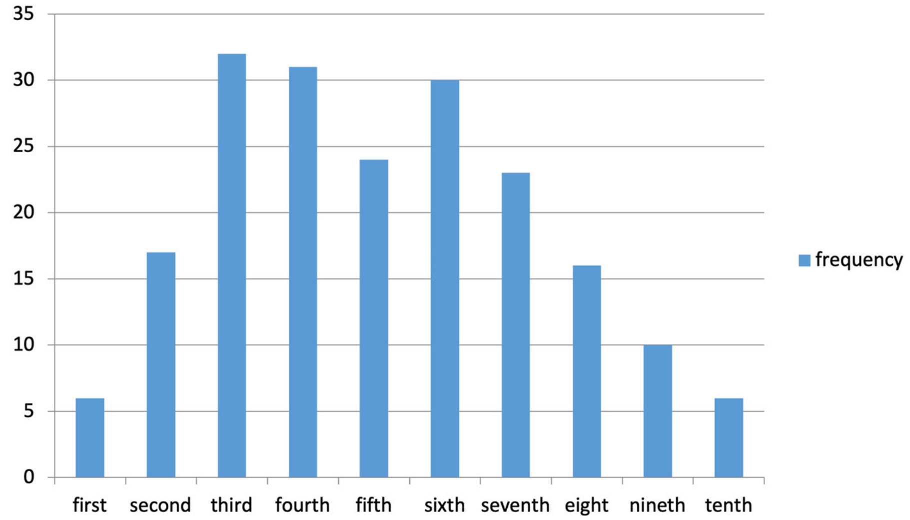

Figure 3. Localization outbreak of septocutaneous perforating vessels of fetal peroneal artery.

Table 2. Final cluster centers: peroneal artery.

	Cluster		
	1	2	3
Peroneal artery	7	20	31

Descriptive statistics for the peroneal artery is presented in Table 1. In order to visualize the previously outlined results, a bar chart was constructed and presented in Figure 3.

Finally, *K*-means cluster analysis was performed on the data set and the variable of interest was number of dissections where septocutaneous perforating vessels of peroneal artery were found (labeled Variable 1). Analysis conducted on Variable 1 showed that, on average, seven septocutaneous perforating vessels were found in cluster 1 ($M = 7$), 20 were found in cluster 2 ($M = 20$) and 31 were found in cluster 3 ($M = 31$). Final cluster centers are presented in Table 2. Analysis also showed that cluster 2 is represented with four cases, while clusters 1 and 3 consist of three cases each. Newly created variable cluster membership provided information that in the first, ninth and tenth 1/10 of the lower leg small number of septocutaneous perforating vessels of peroneal artery was found, while moderate number was found in second, fifth, seventh and eighth 1/10 of fetuses' lower leg. Finally, the lower leg areas with highest number of septocutaneous perforating vessels of peroneal artery are third, fourth and sixth 1/10 (Table 2).

Discussion

In general, lower leg area has been focus of interest of many different research papers and extensive studies. However, knowledge about this body area is still far from complete. While the importance of the topic has been recognized, it is still fairly insufficiently researched (e.g. posterior lower leg skin and its vascular anatomy [11]). Implications of such theoretical gaps extend into the practice. Consequentially, numerous challenges arise such as often quoted poor success rates of lower leg soft tissue reconstruction [12]. A step forward in this area was made with the recognition of importance of fasciocutaneous perforators and flaps. Technological development was one of the biggest obstacles and once when color duplex imaging was introduced, it became feasible to access deep fascia [13]. Pontén reintroduced the concept of the fasciocutaneous flap in the early 1980s as potential surgical solution for soft tissue defects [14]. Thereafter, a long stream of researches followed such as study of Hupkens et al. who conducted an anatomical research in order to localize and classify lateral lower leg perforators [15]. Also, the same author made a significant contribution to the study of medial lower leg perforators, their distribution and characteristics [16]. Apart from anatomical studies focused on general characteristics, a number of published papers revolve around soft tissue reconstruction and the role of fasciocutaneous flaps in the reconstruction process [17,18]. While it is evident that this area of research is becoming more complex and compatible with practical needs, it is important to emphasize that vast majority of studies have been conducted on adults. Studies conducted on children are quite rare (the study by Whaib is one of the very few ones exploring reconstruction of full thickness of soft tissue defect of lower extremities in children [19]), but still more present than studies on fetuses. The study of Ugrenović et al. on neurovascular stalk of the superficial sural flap is one of the few studies published in the literature dealing with human fetuses [20]. Therefore, this field is still under-researched.

We identified several reasons why this research gap should be bridged. Namely, septocutaneous system of lower leg perforators is already very well developed in the fetal period. In addition, there is a rather clear clustering pattern of perforators at different levels which reflects the pattern we subsequently identified in adults. In our previous study conducted on fresh adult Serbian cadavers in 2010 [21], we found that septocutaneous perforators were mostly localized in segments 2/10, 3/10, 5/10 and 7/10, which was not in accordance with findings on fetuses. Initially, we assumed that, during the fetal development, significant changes occur in the vascular bed. However, subsequent analysis of our digital databases (unpublished results) was shown that certain number of septomuscular perforators, especially in segment 2/10, was misinterpreted as septocutaneous. On the other hand, in study conducted by Duc et al. [22] who investigated the distribution, course, origin, number and types of the peroneal artery perforators in 30 legs of 15 adult Vietnamese cadavers, these blood vessels were noted in the greatest number in the 4/10, 6/10 and 7/10 segments, which correspond to segments 4/10, 5/10 and 7/10 in our study. This study, which was in accordance with results obtained by Wei et al. [23], also showed that in all cadavers, a cutaneous perforator was consistently found within 18 mm from the *F* point, which is the junction between the 6/10 and 7/10 segments at the posterior border of the fibular bone. In our study, the position of mentioned point corresponds with the junction between segments 4/10 and 5/10 where a large number of perforators was also recorded in fetuses. In addition, Schaverien and Saint-Cyr also found that even 93% of 20 fresh cadaveric specimens had peroneal artery perforators in the segment between 13 and 18 cm proximal to the lateral malleolus, or at a calculated interval of 0.4–0.5 along the total length of the fibula [24]. Finally, systematic and pooled analysis of peroneal artery perforators for fibula osteocutaneous and perforator flaps conducted by Iorio et al. [25] demonstrated the highest frequency of peroneal perforators at the junction of the middle and distal thirds of the lower leg, with the highest density of septocutaneous perforators at the 0.6 interval. Therefore, it can be concluded that, regardless of the existence of slight inter-ethnic variability, perforator flaps along the lateral part of lower leg that include the skin within the junction of the middle to distal thirds of the fibula axis have the highest probability of perforator capture [25]. Besides, the presence of vascular anastomoses between the main vascular systems of the lower leg allows practically any perforator to be the vascular base ('pivot point') of the flap [21]. However, the largest area of skin that can be harvested safely on a single perforator (perforosome) has not yet been definitively elucidated [26].

On the other hand, analyzing the localization outbreak of septocutaneous perforators of fetal peroneal artery (Figure 3), it is interesting to emphasize that these blood vessels were distributed predominantly centrally, with a peak incidence at the diaphyseal area, which is similar to the results obtained in studies of Schaverien and Saint-Cyr [24], Boriani et al. [27], Iorio et al. [25] and Sur et al. [28]. The possible explanation for this distribution pattern was given by Boriani et al. [27], while the results of our study further support their hypothesis. Namely, unlike the anterior and posterior tibial artery perforators, for which neoangiogenesis is assumed to be stimulated by longitudinal bone growth at the metaphyseal plates, the number of peroneal perforators may be unrelated to leg length, given that their centrally located unimodal distribution is maintained from the fetal to the adult period. Having this in mind, as well as the fact that this system represents the vascular basis of fasciocutaneous flaps, we can conclude that skin and soft tissue defects of distal lower leg area can be taken care of during early childhood by implementing this reconstructive method.

The significance of this research lies in the fact that in this moment pre-operative mapping and identification of perforators using ultrasonographic and color Doppler imaging or magnetic resonance imaging, which generates images with high spatial resolution and represents operator-independent diagnostic modality [29], is significantly easier. Moreover, it is interesting to point out that this mapping is almost not necessary at all since the operative method requires presence of at least one reliable perforator and in this study we showed exact levels of emergence of the most distal perforators. Despite the well-known fact that during embryogenesis and fetal development significant changes occur in the number and caliber of the lower leg vascular vessels as well as obliteration of some blood vessels and creation of new ones, the basic model of blood vessels pattern of this system stays rather stable until its final stage of development.

Disclosure statement

The authors declare that they have no conflict of interest.

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