

Anatomical Analysis of Cutaneous Perforator Distribution in the Forearm

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Background: Few reports describe the distribution of cutaneous perforators from the radial and ulnar arteries in the forearm. This study aimed to map the location of the cutaneous perforators that arise directly from the radial and ulnar arteries in cadavers.

Methods: Twenty-nine human cadaveric forearms were dissected. All radial and ulnar arteries cutaneous perforators were analyzed for total number and distribution. To define the distribution of each cutaneous perforator, the forearm was divided into 10 sections, with the sections labeled as 10%, 20%, 30%, and so on, beginning at the wrist.

Results: From the radial artery, there were a total of 262 skin perforators with an average of 9.03 ± 2.28 (mean \pm SD) per limb, whereas the total was 159 from the ulnar artery, with an average of 5.48 ± 1.49 per limb. Additionally, 128 (49%) radial artery cutaneous perforators and 75 (47%) from the ulnar artery were concentrated in the 0–30% section of the forearm. Both the radial and ulnar arteries had many cutaneous perforators in the forearm section labeled 70%, with 32 of 262 (12%) cutaneous perforators of the radial artery and 27 of 159 (17%) cutaneous perforators of the ulnar artery located here.

Conclusions: There were more cutaneous perforators from the radial artery than from the ulnar artery, and both were concentrated in the distal one-third of the forearm and in the forearm section labeled 70%. This information could be helpful when harvesting forearm flaps. (*Plast Reconstr Surg Glob Open* 2017;6:e1550; doi: 10.1097/GOX.0000000000001550; Published online 26 October 2017.)

BACKGROUND

The forearm perforator flap and free flap are widely used for hand trauma surgeries and head and neck reconstruction, respectively,^{1–5} because the forearm flap is thin and has stable blood supply. The radial artery and its perforators are frequently used as vascular pedicles, but there are also several reports of reconstruction with a forearm flap using the ulnar artery.^{6–10} Both forearm flaps are technically easy to harvest,^{9–12} but it is necessary to include a perforator in the flap when elevating it. Knowledge of the distribution of the cutaneous perforators in the forearm is a key to successful flap and reconstruction surgery. However, only a

few reports have described how the cutaneous perforators are distributed from the radial and the ulnar arteries.^{10,13,14} Hekner et al.¹⁰ reported that no significant difference in the number of clinically relevant perforators was found between the radial and ulnar arteries in the distal segment of the forearm; however, they focused only on the distal third of the forearm and not the entire forearm. Mei et al.¹⁴ reported an anatomic study of the dorsal forearm perforators, but they focused on perforators from the interosseous artery. The aim of this study was to map the location of the cutaneous perforators that arise directly from the radial and ulnar arteries on the entire forearm in cadavers.

MATERIALS AND METHODS

A total of 29 upper limbs from cadavers without a history of trauma or surgery were used in this study. There were 15 right arms and 14 left arms. The subject group consisted of 5 men and 12 women, with a mean age at death of 86.9 ± 10.6 (mean \pm SD) years. The Kawasaki Medical School Department of Anatomy managed preservation by the following perfusion fixation method.

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Embalming Technique

Within 48 hours after the death of the subjects, an arterial embalming technique was employed to prepare the cadavers. This technique consisted of a preembalming treatment with a blood clot disperser (pH-A solution and a cell conditioner, Champion Co., Ltd.), removal of blood clots, draining of blood, and arterial embalming with an embalming apparatus via both the femoral and brachial arteries. The embalming fluid consisted of 95% ethyl alcohol (7.6L), 35% formalin (1.3L) as a fixative, diethylene glycol (2.7L) as a preservative, liquefied phenol (1.3L) as an anti-mold agent, and water (8.0L).¹⁵

Three-Dimensional Arteriography

Following embalming, 10–15mL of a radiopaque contrast (barium sulfate) was injected into the brachial artery via a syringe, with hand pressure. Gelatin was dissolved in barium at a concentration of 5–7%. Gelatin was used for coagulation to prevent leaking after the intravascular injection.¹⁶ Stereoscopic arteriography of the entire arm was performed with an X-ray imaging apparatus (MUX-10, SHIMAZU Co., Ltd., Japan) at a focal spot-to-film distance of 80 cm. The focal spot position was shifted 35 mm to the left and right of the center of the hand to create a pair of stereo-arteriography images (Fig. 1). The arterial patterns were analyzed stereoscopically with a Nikon Stereoscope (Model II, Nikon Co., Ltd., Japan). By employing 3-dimensional analysis of arteriography with the embalming technique described above, it was possible to identify the position and patterns of the forearm arteries and perforators.^{17,18} As a result, we were able to investigate whether there is any indication for

this study before macroscopic dissection. However, since it was difficult to analyze the exact position of the cutaneous perforators, their distribution was confirmed using macroscopic dissection as described below.

Macroscopic Dissection

An incision was made on the volar aspect of the forearm in the wrist crease. A second skin incision was made from the wrist to the elbow crease midway between the ulnar and radial arteries. While preserving the perforators to the skin, medial and lateral skin flaps were elevated.¹⁰ After confirming the whole appearance of the cutaneous perforators, the radial and ulnar arteries were traced to the bifurcation at the brachial artery. The perforators to the muscles were cut (Fig. 2). The lengths of the radial and ulnar arteries were measured from the wrist crease to the bifurcation. The number and positions of the cutaneous perforators were recorded. Forearm length was defined as the distance from the volar aspect of the pisiform bone to the medial epicondyle of the humerus (Fig. 3).^{9–11,19} To make a distribution diagram of each cutaneous perforator, the forearm was divided into 10 sections, with the sections labeled as 10%, 20%, 30%, and so on, beginning at the wrist (Fig. 4).

This study was conducted with the approval of the Kawasaki Medical University Ethics Committee (1391–2; May 18, 2015).

RESULTS

The average length of the forearm from the volar aspect of the pisiform bone to the medial epicondyle of



Fig. 1. Stereoscopic arteriogram (stereogram) of the left forearm. The focal spot position was shifted 35 mm to the left and right of the center of the hand to create a pair of stereo-arteriography images.

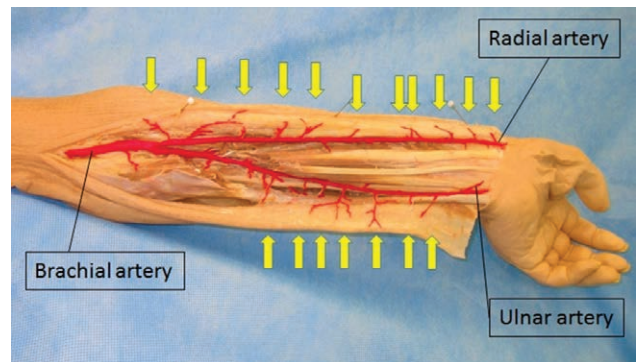


Fig. 2. An anatomical picture of the left forearm. The brachial artery, radial artery, ulnar artery, and perforators are marked in red paint. The yellow arrows indicate the position of the cutaneous perforators. The perforators to the muscle were cut. To show the ulnar artery, the flexor tendons were excised.

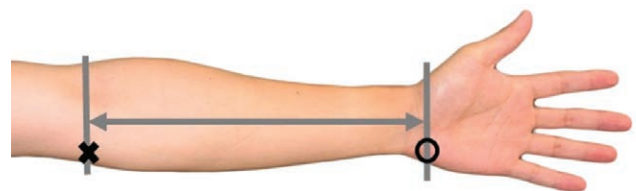


Fig. 3. The forearm length was defined as the distance from the volar aspect of the pisiform bone to the medial epicondyle of the humerus. x: medial epicondyle; o: pisiform bone.

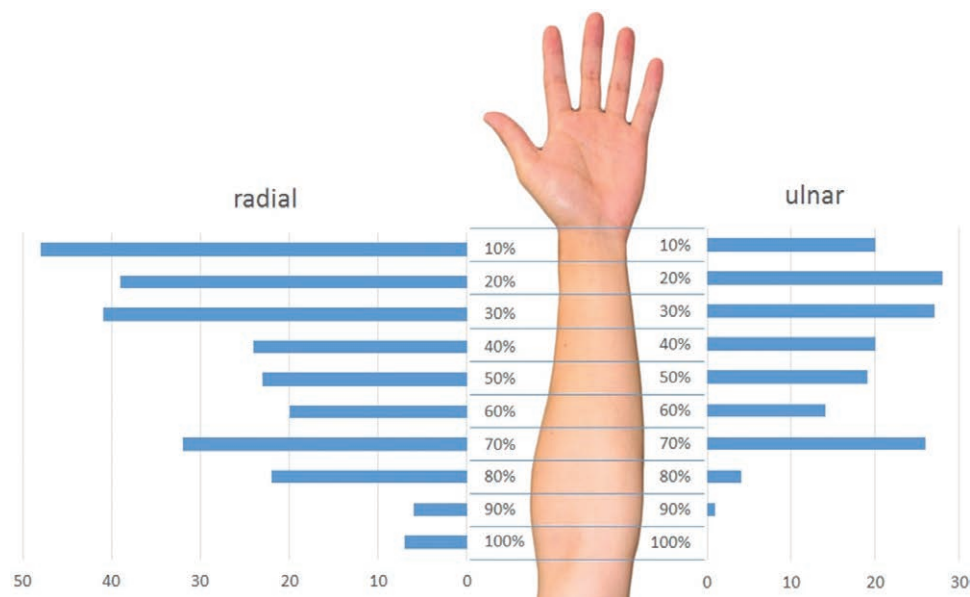


Fig. 4. Distribution diagram of each cutaneous perforator. The forearm was divided into 10 sections.

the humerus was 22.8 ± 1.58 cm (mean \pm SD). The mean length from the wrist crease to the bifurcation of the radial and ulnar arteries was 20.3 ± 2.07 cm and 20.2 ± 1.74 cm, respectively. The total number of skin perforators was 262 from the radial artery, with an average of 9.03 ± 2.28 per limb, and 159 from the ulnar artery, with an average of 5.48 ± 1.49 per limb (Table 1). The mean distance between the perforators was 2.29 ± 0.63 cm for the radial artery and 2.82 ± 0.84 cm for the ulnar artery (Table 2). Furthermore, the average distance was shorter (1.65 cm) in the distal one-third of the radial side and proximal of the ulnar side. Of the 262 cutaneous perforators in the radial artery, 128 (49%) were located in the 0–30% sections of the forearm. Likewise, of the 159 cutaneous perforators of the ulnar artery, 75 (47%) were also located in the 0–30% sections of the forearm. Both the radial artery and the ulnar artery also had many cutaneous perforators within the 70%

section of the forearm; 32 of the 262 (12%) cutaneous perforators of the radial artery and 27 of the 159 (17%) cutaneous perforators of the ulnar artery were located here (Fig. 4). Two radial arteries, 1 in a female right limb and 1 in a female left limb, did not join the ulnar artery at the forearm. Anatomic variation of a radial artery derived from the superficial brachial artery was observed.

DISCUSSION

In this study, there was no difference in the distance from the wrist crease to the bifurcation of the radial and ulnar arteries. In other words, there is no difference in the length of the vascular pedicle when a forearm flap is harvested; approximately 20 cm can be included, and there is no problem with reconstructing the head or neck with a forearm free flap, using the ulnar artery.^{1,4,5,8,10}

Table 1. Length of the Artery and Average Number of Cutaneous Perforators in 1 Limb (15 Right Arms and 14 Left Arms)

	Radial Artery (Mean \pm SD)	Ulnar Artery (Mean \pm SD)	Mean Difference	P*
Length of the artery† (cm)	20.3 ± 2.07	20.2 ± 1.74	0.1	0.31
Average number of cutaneous perforators in 1 limb	9.03 ± 2.28	5.48 ± 1.49	3.55	< 0.01

*Paired *t* test.

†The length from the wrist crease to the bifurcation of the radial and ulnar arteries.

Table 2. The Mean Distance between Perforators

Section of the Forearm	Radial Artery		Ulnar Artery	
	No. Perforators	Mean Distance (cm; Mean \pm SD)	No. Perforators	Mean Distance (cm; Mean \pm SD)
Overall	262	2.29 ± 0.63	159	2.82 ± 0.84
Distal (0–30%)	128	1.65 ± 0.58	75	2.38 ± 0.98
Middle (31–60%)	67	2.73 ± 1.09	53	2.62 ± 1.38
Proximal (61–100%)	67	2.81 ± 0.98	31	1.65 ± 0.98

Traditionally, the radial artery-based forearm flap has been frequently used for reconstruction in the head and neck area, but recently the ulnar artery-based forearm flap has been drawing attention. Several studies report the benefits of the ulnar artery forearm flap when compared with the radial artery forearm flap.^{9–11,19} Mathy et al.⁹ and Yu et al.¹¹ have shown that the ulnar artery forearm flap has several advantages, including having less hair, the ability to close the donor site directly, having less obtrusive location of scar, and having a low incidence of wound healing problems such as flexor tendon exposure, stiffness, sensory loss, cold intolerance, and injury to the radial nerve.

The average number of cutaneous perforators per forearm was 9.03 for the radial artery and 5.48 for the ulnar artery. There are few reports comparing the number of these cutaneous perforators in the forearm.^{10,13,14} Hekner et al.¹⁰ reported that no significant difference in the number of clinically relevant perforators was found between the radial and ulnar arteries in the distal segment of the forearm; however, in the proximal half of the distal segment, more perforators were derived from the radial artery than from the ulnar artery. In this study, the number of cutaneous perforators from the radial artery was significantly larger in the entire forearm, especially in the distal segment. Therefore, the forearm flap on the side of the radial artery is more likely to secure cutaneous perforators, and the flap design is more flexible when harvesting the forearm flap.

In this study, it is important to note that the cutaneous perforators were concentrated in the distal one-third and within the 70% section of the forearm. Hanker et al.¹⁰ reported that most perforators were located in the distal segment of the forearm, and Mathy et al.⁹ reported the presence of many cutaneous perforators around the midpoint of the forearm. Because of the increased concentration of perforators in the 0–30% sections of the forearm, the forearm flap is best harvested from the distal one-third of the forearm. This makes it possible to create a cutaneous perforator flap at a position closer to the hand in the case of hand surgery,^{6,12,20} and in the case of a free flap, a long vascular pedicle can be harvested, which is considered to be useful for head and neck reconstruction.¹⁰ Our study found that, and this is particularly important, both the radial artery and the ulnar artery had more cutaneous perforators in the 70% section of the forearm than in the surrounding area. This finding is supported by several reports^{6,9,11,19,21} that found that cutaneous perforators are densely present between the center to the proximal one-third of the forearm. This flap can be used as a reverse pedicle forearm flap^{12,22,23} or free flap in the reconstruction of the hand.^{9,19} It has also been reported that the pedicle perforator flap that includes these perforators can be used in the reconstruction of the elbow.^{6,24} The extent of the indications for reconstruction with a forearm flap is remarkable.

The average distance between the cutaneous perforators was 2.29 cm in the radial artery and 2.82 cm in the ulnar artery. Additionally, in the distal one-third of the radial side, the average distance was short (1.65 cm), reflecting that the perforators were densely concentrated. On the

other hand, in the proximal part, it was longer than the overall mean distance (2.81 cm). This includes not only the 70% section but also other sections with fewer perforators; therefore, it is inevitable that the distance between the perforators will be more. Conversely, in the proximal part on the ulnar side, it was seen that the distance between the perforators narrowed because there were many perforators in the 70% section and almost none were seen in other sections. From this result, when designing a flap, the number of cutaneous perforators contained in the flap can be predicted from the size of the flap. We would like to apply this finding clinically while harvesting flaps for reconstruction.

In this study, anatomic variation of the radial artery derived from the superficial brachial artery was observed in 2 of the 29 limbs (6.9%). According to past reports, Adachi²⁵ reported a similar arterial anatomic variation in 14 of 410 (3.4%) Japanese individuals, and Müller²⁶ reported this variation in 3 of 100 (3%) Swedish individuals. Although it is relatively rare, this anatomic variation should be kept in mind when elevating the free forearm flap. Performing a preoperative examination such as angiography to confirm the blood flow and location of the artery will lead to safer and more successful surgeries.

In discussing the anatomy of the perforators, it is very important to consider whether the flap will survive in each cutaneous perforator. In other words, how much of the flap is perfused by 1 cutaneous perforator must be considered. Saint-Cyr et al.²⁷ reported that each perforator holds a unique vascular territory, which they termed “perforasome.” Direct and indirect linking vessels play a critical part in perforator flap perfusion.^{27–30} In this study, the distribution of cutaneous perforators became clear, but the contribution of each perforator to the perfusion is unknown. It is necessary to investigate the vascular cutaneous territories of the perforators. For example, Saint-Cyr et al.⁶ cannulated the major perforator from radial artery and injected methylene blue to identify the perforator flap territory. However, in our study, we could not stain the skin because we used embalmed cadavers, instead of fresh ones. In considering the perfusion of a perforator, the diameter and length of perforator are also important. Saint-Cyr et al.⁶ and Mathy et al.⁹ categorized the perforators based on whether the diameter was at least 0.5 mm. If the diameter of a perforator is less than 0.5 mm, it is suggested that sufficient perfusion may not be secured. Also, the length of perforator is important in securing long pedicle in the perforator flap. However, these items could not be measured in this study for the same reason as above. These were the limitations of our study.

CONCLUSIONS

The distribution of the cutaneous perforators from the radial artery and ulnar artery in the forearm was analyzed. There were more cutaneous perforators from the radial artery than the ulnar artery, both of which were concentrated in the distal one-third and in the 70% section of the forearm. This information could be helpful when harvesting forearm flaps.

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