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Anatomical Study of Perfusion of a Periosteal Flap with a Lateral Pedicle

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Background: Pedicled periosteal flaps are commonly used for tissue defects between the base of the skull and the midfacial area. This study aimed to clarify the 3-dimensional vascular distribution of temporal region flaps.

Methods: Ten fresh cadavers were used. Full-thickness cranial flaps were elevated from the cranial bone and each layer was detached separately. Contrast enhancement of the full thickness of the scalp, macroscopic evaluation, and histologic analyses were performed. Radiographs were obtained and image analysis was performed using a 3-dimensional monitor.

Results: The mean number of deep vessels extending from the parietal branch of the superficial temporal artery was 68.7, including 14.2 and 54.5 vessels on the proximal and distal sides, respectively. The mean number of deep vessels extending from the frontal branch of the superficial temporal artery was 71.6, including 17.6 and 54.0 vessels on the proximal and distal sides, respectively. There were significantly more perforating branches in the distal area than in the proximal area of both the frontal and parietal branches ($P = 0.005$). There was no significant difference in the number of perforating branches between the frontal and parietal branches.

Conclusions: Contrast-enhanced images of the loose areolar tissue and periosteal layers revealed vessels that extended radially. We successfully identified the 3-dimensional structure of the perforating vessels peripheral to the temporal fossa. Our findings provide a theoretical foundation for the feasibility of elevating a periosteal/loose areolar tissue flap with a reliable blood supply without sacrificing the temporal muscle. *(Plast Reconstr Surg Glob Open 2017;5:e1476; doi: 10.1097/GOX.0000000000001476; Published online 19 September 2017.)*

INTRODUCTION

Tissue defects from the base of the skull to the central facial region that result from tumor resection or trauma can be reconstructed using a range of skin, muscle, and periosteal flaps. Various materials are available for soft-tissue reconstruction, including forehead, scalp, galeal, temporalis, and cranial periosteal flaps; however, when hard tissue reconstruction is required, periosteal flaps with cranial bone attached are often used. A wide range of elevation methods and designs for skin flaps have been previously reported.[1–6] Their greatest advantage is that they can be used with a pedicle, making them safer and less invasive than free skin flaps taken from distant sites.[7] For skin flaps with an anterior pedicle, the main blood supply route is via the supratrochlear and supraorbital arteries.[8–13] For flaps with a lateral pedicle, the main blood supply route is via the deep temporal and superficial temporal arteries.[14] This vascular distribution of lateral pedicles has many advantages, making them the ideal reconstruction material.[10,15] However, the parietal area has complex anatomy, with several layers of membrane structures. The lack of consistent nomenclature for these membrane structures makes them even more difficult to grasp.[16] Many aspects of vascular distribution in the parietal region remain unclear; therefore, more in-depth studies are required. We

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clarified the 3-dimensional (3D) vascular distribution of the parietal region for safer, more reliable elevation of skin, muscle, musculocutaneous, and periosteal flaps with a lateral pedicle.

MATERIALS AND METHODS

We used fresh cadavers donated with consent to the Department of Anatomy of Keio University. Ten fresh cadavers were used, none of which had an existing incision in the cranial region.

The bilateral common carotid and major femoral arteries were cannulated and the cadavers were injected systematically with a lead oxide–gelatin mixture. A number 10 scalpel was used to make an incision from the cranial midline in the sagittal direction from the height of a line joining both eyebrows as far as the posterior tubercle to a depth just below the galea. A horizontal incision was made in the forehead from the upper margins of the eyebrows, and this incision was continued laterally at the height of the inferior margin of the external auditory meatus to include the auricle until it reached the posterior tubercle. Full-thickness specimens were elevated and each layer was carefully detached with the use of a 2.5× magnifying glass to avoid damaging the membrane structure; after which, it was investigated macroscopically and radiographically. Radiographs of all specimens were obtained using soft X-ray equipment (SOFTEX; Softec, Inc., Tokyo, Japan).

Experiment 1

Full-thickness cranial flaps were elevated from the cranial bone, and each layer was detached separately. They were investigated by macroscopic examination, and histopathological tests were performed.

Experiment 2

Full-thickness cranial flaps (consisting of skin, galea, loose areolar tissue, and periosteal membrane) were elevated from the cranial bone. Each layer was resected separately, starting from the skin. Radiographs were obtained and blood vessel courses were examined in 2 dimensions. The following specimens were contrast-enhanced and underwent X-ray imaging: (1) the galeal, loose areolar tissue, and periosteal membrane layers with the skin removed; (2) the loose areolar tissue and periosteal membrane layers with the skin and galea removed; (3) the loose areolar tissue layer alone; and (4) the periosteal membrane layer alone.

Experiment 3

After contrast enhancement of the full thickness of the scalp, radiographs were obtained and image analysis was performed using a 3D monitor. The perforating branches of the parietal and frontal branches of the superficial temporal artery (STA-P and STA-F) running through the deep side of the scalp (the loose areolar tissue side) were counted on 3D contrast-enhanced imaging of the full thickness of the scalp. The total lengths of the blood vessels from the bifurcations of the STA-F and STA-P to their distal points were divided into proximal and distal segments of equal length and the perforating branches in each area were counted.

The full-thickness scalp specimens were imaged from 2 directions to enable stereoscopic observation. Radiographs were imported to a computer and 3D conversion software and a 3D monitor were used to analyze the courses and numbers of perforating vessels running from the STA into the deeper area.

Statistical Analysis

Statistical analysis was performed using SPSS software to perform the Wilcoxon signed rank test as a nonparametric test.

RESULTS

Experiment 1

The skin and the galea, loose areolar tissue, and periosteal membrane layers were detached separately. During dissection, the tissues of the galea and periosteal layers were robust even under strong traction. The loose areolar tissue was fragile and tore when it was placed under traction, but it was able to be elevated without problems as long as great care was taken during this procedure (Fig. 1).

Histopathological examination by hematoxylin and eosin (HE) staining from the skin to the periosteal layer

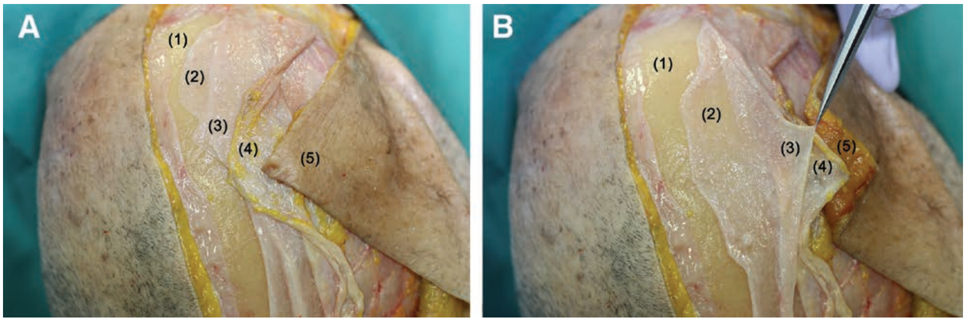


Fig. 1. Findings upon detachment of the scalp, galea, loose areolar tissues, and periosteal layers. During dissection, the tissues of the galea and periosteal layers were robust even under strong traction. A, The loose areolar tissue was fragile and tore when it was placed under traction, but its elevation was possible as long as great care was taken during this procedure. B, The loose areolar tissue is elevated. (1) Skull; (2) periosteum; (3) loose areolar tissue; (4) galea; and (5) scalp.

also revealed the skin and the galea, loose areolar tissue, and periosteal membrane layers separately (Fig. 2).

After branching off the maxillary artery in the parotid gland at the height of the mandibular neck, the STA runs upward on the superficial side of the posterior root of the zygomatic process, passing through the galea to run above it at this height. During subgaleal detachment, numerous perforating branches leading off the STA into the loose areolar tissue layer were readily visible to the naked eye (Fig. 3).

Experiment 2

Abundant vascular structures were evident throughout the specimens (Fig. 4) and peripheral vascular territories were observed extending radially. The STA did not reach the midline in any subject (Fig. 4).

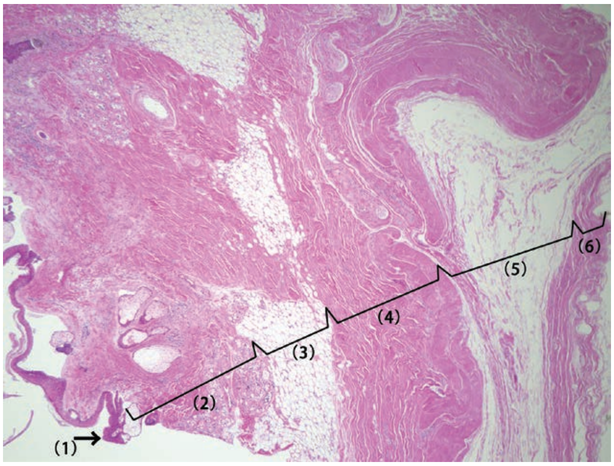


Fig. 2. Histopathological findings for HE staining from the scalp to the periosteal layers. (1) Arrow: epidermis; (2) dermis; (3) subcutaneous fat; (4) galea; (5) loose areolar tissue; and (6) periosteum. Similar to macroscopic findings, these could be separated into each layer of the scalp, galea, loose areolar tissues, and periosteal layers.

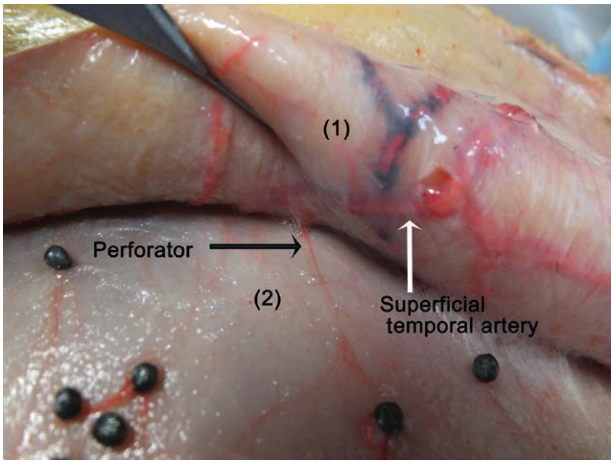


Fig. 3. Findings during subgaleal detachment. (1) Galea; (2) loose areolar tissue. The black spots indicate where the perforator was resected when detached. Penetrating branches (black arrow) leading off the STA (white arrow) through the galeal layer into the loose areolar tissues were readily visible to the naked eye. Black spots were marked off at locations where incisions were made at the penetrating branch leading from the STA to the loose areolar tissues. The size of the penetrating branches is visible even in this photograph.

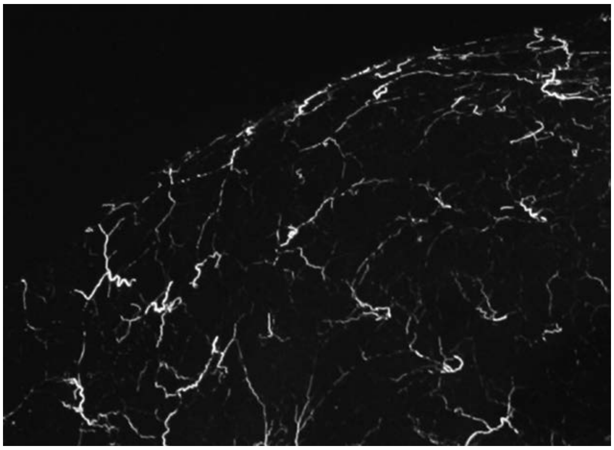


Fig. 4. Findings of specimen. Radiograph of the layer below the right half of the galea with an incision in the cranium along the sagittal suture. An abundance of vascular structures can be observed extending radially. Abundant vascular structures were evident throughout the specimens and peripheral vascular territories were observed extending radially.

For specimens in (Fig. 5A), no large vessels were present at any site in the forehead, temporal, parietal, or occipital regions, but fine vessels were evident. These formed a dense, albeit irregular, vascular structure. A network of fine vessels was also present in the midline area, with anastomoses between fine vessels on the left and right crossing the sagittal suture (Fig. 5B).

A comparison of specimens in (Fig. 6A) with those of specimens in (Fig. 6B, C) before detachment at the same sites revealed that there were few vascular structures in the periosteum alone and that the dense network of vessels present in specimens in (Fig. 6B; the loose areolar tissue and periosteal layers) was absent, although a few vessels could be seen (Fig. 6C).

Experiment 3

Tables 1, 2 show the results of an analysis of the number of perforating vessels from the STA. The mean number of direct branches running into the deeper area (the loose areolar tissue and periosteum) from the parietal branch of the STA-P was 68.7. The mean number of perforating vessels on the proximal side was 14.2; on the distal side, it was 54.5.

The mean number of direct branches running into the deeper area (the loose areolar tissue and periosteum) from the frontal branch of the STA-F was 71.6. The mean number of perforating vessels on the proximal side was 17.6; on the distal side, it was 54.0.

Results of Statistical Analysis

For the frontal branch of the STA, the median values were 13 proximal and 54 distal. There were significantly more perforating branches in the distal area ($P = 0.005$).

For the parietal branch of the STA, the median values were 12.5 proximal and 51.5 distal. Here, too, there were

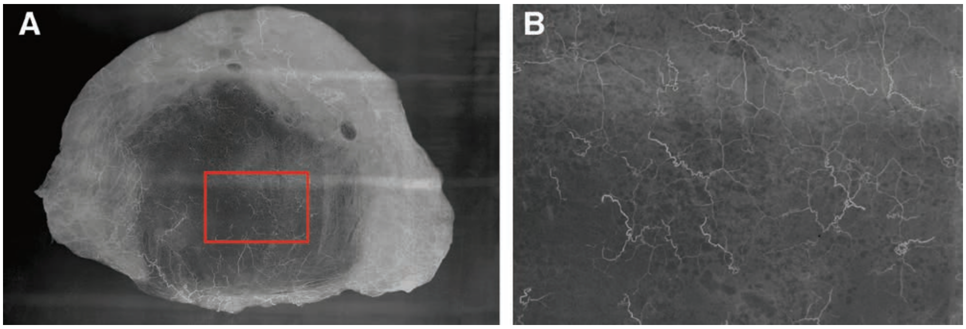


Fig. 5. Findings of specimen. Contrast-enhanced radiographic image of the midline area of the loose areolar tissue/periosteum. A ramified structure of fine blood vessels is also present in the midline area, and anastomosis between the fine vessels on the left and right can be found, crossing the sagittal suture. Irregular vascular structures were visible. A network of fine vessels was also present in the midline area, with anastomoses between fine vessels on the left and right crossing the sagittal suture (A). A magnified image of the part of the image in (A) enclosed in the red square (B).

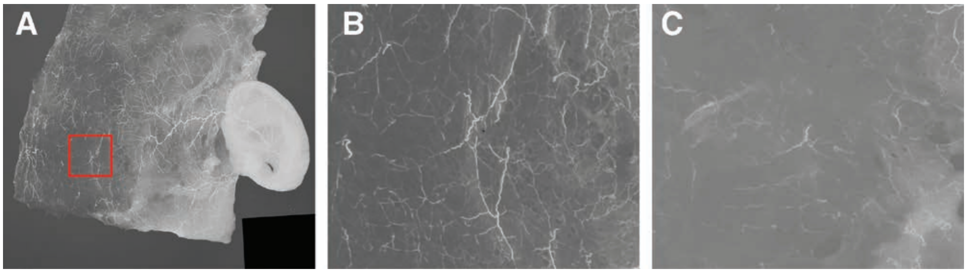


Fig. 6. Findings of periosteum. A, A contrast-enhanced radiograph of loose areolar tissues and periosteum. B, A magnified image of the part of the image in (A) enclosed in the red square. C, An image of the part same as (B). It shows findings of only the periosteum after the loose areolar tissue had been removed from it. C, Revealed very few vascular structures and a few vessels; however, the dense network of vessels observed in (B) was not visible here.

Table 1. Penetrating Branches Running through the Deep Side (the Loose Areolar Tissue and Periosteal Side) of the Frontal Branch (STA-F) and Parietal Branch (STA-P) of the STA

Case	STA-F Proximal (No. Extending Branches)	STA-F Distal (No. Extending Branches)	STA-P Proximal (No. Extending Branches)	STA-P Distal (No. Extending Branches)
1	13	78	13	56
2	7	55	18	28
3	18	80	19	52
4	34	36	12	85
5	49	70	30	110
6	19	73	12	45
7	12	53	13	72
8	13	33	11	51
9	8	17	6	9
10	3	45	8	37

The mean number of direct branches running into the deeper area (the loose areolar tissue and periosteal side) from the parietal branch of the STA-P observed in 10 cases was 68.7. The mean number of perforating vessels on the proximal side was 14.2; while that on the distal side, it was 54.5. The mean number of direct branches running into the deeper area (the loose areolar tissue and periosteal side) from the frontal branch of the STA-F was 71.6. The mean number of perforating vessels on the proximal side was 17.6; while that on the distal side, it was 54.0.

significantly more perforating branches in the distal area ($P = 0.005$).

There was no significant difference between the frontal and parietal branches in terms of the number of branches (Table 2).

DISCUSSION

Skin flaps are a type of cranial tissue frequently used for the reconstruction of craniofacial defects.[1–5] Pericranial flaps, which are mainly used to block off the intracranium and the nasal sinuses after anterior skull base tumor removal, are particularly useful.[8] The major advantage of pericranial flaps is that they are pedicled and thus possess a blood supply.[7] Free skin flaps harvested from distant sites may also be used for basicranial reconstruction, but these require vascular anastomosis and thus entail risk. The use of pericranial flaps reduces the risk associated with vascular anastomosis, making them a safer choice for reconstruction. Pericranial flaps may gain their blood supply

Table 2. Statistical Analysis using Wilcoxon Signed-Rank Test

		Percentile		
Descriptive Statistics	**Frequency**	**25**	**50 (Median)**	**75**
STAFp	10	7.75	13.00	22.75
STAPp	10	10.25	12.50	18.25
STAFd	10	35.25	54.00	74.25
STAPd	10	34.75	51.50	75.25
Wilcoxon signed-rank test	Frequency	Mean Rank	Rank Sum	
STAFd-STAFp	0*	0.00	0.00	
Negative rank	10†	5.50	55.00	
Positive rank	0‡			
Same rank	10			
Total				
STAFd-STAFp	0	0.00	0.00	
Negative rank	10	5.50	55.00	
Positive rank	0			
Same rank	10			
Total				
STAFp-STAFp	5	6.00	30.00	
Negative rank	4	3.75	15.00	
Positive rank	1			
Same rank	10			
Total				
STAFd-STAFd	6	4.83	29.00	
Negative rank	4	6.50	26.00	
Positive rank	0			
Same rank	10			
Total				
Statistical Tests	STAFd-STAFp	STAFd-STAFp	STAFp-STAFp	STAFd-STAFd
Z	−2.803†	−2.803†	−0.890‡	−0.153‡
Asymptotic *P*	0.005	0.005	0.373	0.878

For the frontal branch of the STA, the median values were 13 proximal and 54 distal. There were significantly more perforating branches in the distal area (P = 0.005). For the parietal branch of the STA, the median values were 12.5 proximal and 51.5 distal. Here, too, there were significantly more perforating branches in the distal area (P = 0.005). There was no significant difference between the frontal and parietal branches in terms of the number of branches (Fig. 2).
*Wilcoxon signed-rank test.
†Based on negative rank.
‡Based on positive rank.

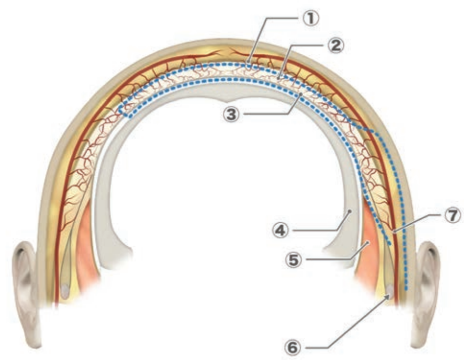
via either an anterior vascular pedicle or a lateral pedicle. Pericranial flaps with an anterior pedicle are supplied via the supratrochlear and supraorbital arteries, and some authors regard this blood supply as unstable.[9] If pericranial flaps with a lateral pedicle include the temporal muscle, then they are supplied via the deep parietal artery. Use of the temporal muscle is undesirable in cosmetic terms, however, because this causes a depression in the temporal fossa. This depression can be corrected artificially with a titanium mesh or similar device, but this increases the risk of complications due to the use of a foreign body. In some cases, when the skull base defect is larger than 40 × 40 mm, free abdominal flaps can be considered if some amount of volume is needed.

Pericranial flaps can be applied to the area where sufficient volume is not required for reconstruction. It can be utilized to block the passage to the paranasal sinus (frontal sinus, ethomoidal sinus, cellulitis). Previously, while elevating the perfused periosteum, the temporal muscle was also elevated. However, this method does not use the temporal muscle; thus, there is no appearance of deformity at the temporal area.

We regard the use of flaps that do not include the temporal muscle (and thus do not use the deep temporal artery) as important; therefore, we have focused on flaps that make use of the STA.

We dissected fresh cadavers to reconfirm the membrane structure of the temporal region and investigated the 3D course of the STA. It is well known that the blood flow to periosteal flaps comes from the deep temporal artery via the temporal muscle.[10,12,15,17] In this study, however, elevation and macroscopic observation of the periosteum alone revealed only a small number of perforations by perforating branches, with little vascular tissue visible to the naked eye. Contrast-enhanced X-ray imaging also revealed few contrast-enhanced vessels. These findings suggested that the periosteum itself contains little vascular tissue. The flaps usually described as pericranial flaps must also include loose alveolar tissue if they are to be used as reconstruction tissue with a good blood supply because perfusion of the periosteum by itself is poor.

Other than the deep temporal artery via the temporal muscle, the main source of blood supply to periosteal flaps with a lateral pedicle is the STA. The STA branches off the external carotid artery toward the superficial layers, running above the galea and giving rise to branches in the temporal region; after which, it bifurcates into the frontal branch (STA-F), which runs toward the forehead and the parietal branch (STA-P).[17–21] Although some authors contend that the temporal muscle must also be elevated to ensure the safe elevation of the periosteal flap with a vascularized lateral pedicle,[7] our 3D contrast-enhanced examination revealed numerous perforating branches from the STA into the loose areolar tissue that reach areas peripheral to the temporal muscle, suggest-



① Galea ② Loose areolar tissue ③ Periosteum ④ Cranium
⑤ Temporalis muscle ⑥ Zygomatic arch ⑦ Superficial temporal artery
Blue dotted line: periosteal flap lift line

Fig. 7. Findings of dense vascular network. The blue dot line in this schema shows the lift line of the periosteal flap with a lateral pedicle and blood flow. Findings of a dense vascular network on both the left and right crossing the midline, and numerous perforating vessels from the STA to the lose areolar tissues suggest that inclusion of the loose areolar tissues may make it possible to elevate a periosteal flap with sufficient blood flow.

ing that it may be possible to elevate a periosteal flap with sufficient blood flow even without elevating the temporal muscle (diagram in Fig. 7). Some studies have also stated that because periosteal flaps are supplied with blood separately on the left and right, those that are elevated across the midline will not survive.[8,22,23] In this study, the STA itself did not cross the midline in any of the cadavers examined. However, angiography revealed that periosteal flaps containing loose areolar tissue contained a dense vascular network on both the left and right and crossed the midline (Fig. 5), suggesting that periosteal flaps elevated across the midline may still be able to survive. When the STA was elevated as the vascularized pedicle, we found no significant difference in the number of penetrating branches running toward the periosteum regardless of whether the frontal branch or the parietal branch was used, suggesting that adequate blood supply is not a problem regardless of which of these is utilized as the pedicle. We also found that there were more perforating branches on the peripheral side compared with the proximal side, suggesting that the elevation of periosteal flaps with a reliable blood flow may be feasible even in peripheral areas. Although in this study we were unable to clearly identify the respective territories of the perforating vessels running from the STA toward the loose areolar tissue and the periosteum, contrast-enhanced images of the loose areolar tissue and periosteal layers revealed vessels that extended radially. The detailed identification of the regions supplied by these vessels is a subject for future research. We successfully identified the 3D structure of the perforating vessels peripheral to the temporal fossa. Our findings provide a theoretical foundation for the feasibility of elevating a periosteal/loose areolar tissue flap with a reliable blood supply without sacrificing the temporal muscle.

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