Detailed Vascular Anatomy and Flap Harvest Technique of the Serratus Anterior and Rib Composite Flap

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Short Running Head: Serratus Anterior/Rib Flap Vascularity

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ABSTRACT

Background: The hemodynamics of blood flowing from the anterior serratus to the ribs has yet to be analyzed in detail in serratus anterior/rib composite flaps. We focused on new blood circulation whereby the slip arteries, branching from the serratus anterior branch, off the thoracodorsal artery and the intercostal arteries directly via the interconnecting vessels (axial route). We analyzed in detail the hemodynamics of serratus anterior/rib composite flaps and developed a new method for flap elevation.

Methods: The axial route was identified and analyzed by performing macroscopic autopsies of formalin perfusion-fixed cadavers involving three-dimensional computed tomography angiography and vascular corrosion casting. Flap elevation was performed with new blood circulation, which included the axial route, and blood flow was evaluated using indocyanine green (ICG) fluorescence angiography.

Results: The interconnecting vessels penetrated the intercostal muscles at a mean distance of 4.5 cm from the anterior margin of the attachment sites of the serratus anterior muscle to the ribs and at a mean distance of 7.4 cm from the costochondral junction. The interconnecting vessels had a mean diameter of 0.5 mm. Vascular corrosion casting helped identify multiple capillaries that were distributed from the intercostal arteries to the periosteum of the ribs. Additionally, intraoperative ICG fluorescence angiography confirmed blood flow from the slip arteries to the intercostal arteries.

Conclusions: Good blood flow in harvested graft tissue can be achieved by including the axial route with the periosteal blood circulation at the rib attachment sites of the serratus anterior in a serratus anterior/rib composite flap.

1. Introduction

Since Richards et al.[1] reported the use of a serratus anterior/rib composite flap for mandibular reconstruction in 1985, such flaps have been widely used for reconstructive surgery of the head and neck[2-8] and for limb reconstruction.[2, 9-16] A serratus anterior/rib composite flap offers numerous advantages, including the ability to be elevated as a composite tissue with a latissimus dorsi musculocutaneous flap by using the thoracodorsal blood vessels as a vascular pedicle. The vascular anatomy of serratus anterior/rib composite flaps has been analyzed previously using dye injection, contrast-enhanced radiography, and vascular corrosion casting. It was shown that blood flow from the serratus anterior branch of the thoracodorsal artery was considered the periosteal blood circulation (hereafter referred to as the periosteal route) in which the serratus anterior branch of the thoracodorsal artery flows retrograde to the costal periosteum through a vascular network[1, 2, 8, 11, 17, 18] around the sites of attachment of the serratus anterior muscle to the ribs.

Based on previous reports, we elevated the flap while preserving the periosteum and intercostal arteries around the sites of attachment of the serratus anterior muscle to the ribs. Furthermore, we used them for reconstructive surgery of the head and neck, such as maxillary reconstruction and mandibular reconstruction. Thus far, there have been no literature reviews of the survival rates of serratus anterior/rib composite flaps. However, in our own experience, osteonecrosis due to insufficient blood flow in the grafted bone despite no trouble with vascular anastomosis was exhibited in 6 cases (14%) of 42 cases; therefore, we doubted the stability of the blood circulation from the periosteal route via the vascular network. Godat et al. and Lifchez et al. conducted a detailed analysis of the path of the serratus anterior branch of the thoracodorsal artery inside the serratus anterior muscle.[19, 20] They reported that it branched slip arteries into each serratus anterior muscle slip[19, 20] (Fig. 1), and that the periphery of the slip arteries joined the intercostal arteries directly through penetrating vessels.[19] The report did not examine in detail the localization and diameter of the penetrating vessels. Therefore, in our study, we focused on a series of vessels allowing for blood flow from the slip arteries into the intercostal arteries and considered that including those vessels may help improve blood flow in serratus anterior/rib composite flaps. In a previous report, Godat et al.[19] termed those penetrating vessels “intercostal perforators.” However, because those blood vessels linked slip arteries in the flaps to intercostal arteries, we termed them “interconnecting vessels.”

The purpose of this research was to conduct a cadaver study aimed at analyzing the hemodynamics of new blood circulation mediated by the interconnecting vessels in the serratus anterior/rib composite flap and to clarify the localization and diameter of interconnecting vessels as well as the distribution of vascular networks from the intercostal arteries into the ribs. Based on the aforementioned anatomical findings, we also aimed to develop a new method of elevating the serratus anterior/rib composite flap with good blood flow.

2. Materials and Methods

This study was approved by the Institutional Review Board of Okayama University Medical School.

Cadaver Dissection

Macroscopic autopsy was performed for 7 formalin perfusion-fixed cadavers (14 total sides) to identify the interconnecting vessels and confirm the axial route under direct vision. First, the serratus anterior branch of the thoracodorsal artery was identified through a lateral chest incision. To facilitate the identification and dissection of blood vessels, resin (Mercox II Resin and Catalyst: Ladd Research Co., Ltd., Williston, VT, USA) was injected into the serratus anterior branch of the thoracodorsal artery, and blood vessels were stained and cured. Then, the subcutaneous layer of the anterior chest was dissected at the superficial layer of the serratus anterior muscle up to the areas of the costochondral junction. Blood vessel dissection was performed using a 2.5-times magnifying glass (SurgiTel Co., Ltd., Ann Arbor, MI, USA), and the slip arteries in the serratus anterior muscle, which were attached to areas on the sixth to eighth ribs, were dissected up to the intercostal arteries. Additionally, measurements were performed to determine the vascular diameter at the site of penetration of the interconnecting vessels into the intercostal muscles and the distance from the interconnecting vessels to the anterior margin of the attachment sites of the serratus anterior muscle to the ribs. We used a scale (Crack Scale 58698; Shinwa Rules Co., Ltd., Niigata, Japan) to measure the external vessel diameters of the interconnecting vessels.

Three-Dimensional Computed Tomography Angiography

Contrast-enhanced computed tomography (CT) was performed for 30 formalin perfusion-fixed cadavers (60 total sides) to construct a three-dimensional image of the hemodynamics of the blood flow in the serratus anterior/rib composite flap and to examine the localization of interconnecting vessels. A 4-cm incision was made in the axillary region, and the thoracodorsal artery was identified. The serratus anterior branch of the thoracodorsal artery was preserved, and the latissimus dorsi branch of the thoracodorsal artery as well as the angular branch were ligated. An 18-gauge blunt needle (1.2-mm diameter; Terumo Co., Ltd., Tokyo, Japan) was inserted in the thoracodorsal artery, and a contrast medium (Iomeron 350; Bracco-Eisai Co., Ltd., Tokyo, Japan) was injected using a syringe driver (Terumo TE-331S; Terumo Co., Ltd., Tokyo, Japan). The iodinated contrast medium, which was heated to 50°C to reduce the viscosity, was injected at an infusion rate of 150 ml/h. A volume of 5 ml of iodinated contrast medium was required to achieve optimal filling of the vascular territory of each slip artery. Next, CT of the entire chest wall was performed (Toshiba Alexion TSX-032A; Toshiba Co., Ltd., Tokyo, Japan). Regarding CT properties during the imaging process, power settings were typically set at 120 kV and 150 mA, and the slice thickness was 0.5 mm. The resulting images were reconfigured on a workstation (AZE VirtualPlace; AZE Co., Ltd., Tokyo, Japan). The interconnecting vessels in the areas ranging from the sixth to eighth ribs were analyzed. Because the serratus anterior muscle was impossible to visualize on CT images, we calculated the distance between the interconnecting vessels and the areas of the costochondral junction.

Anatomical Corrosion Casting

Casting was performed to visualize the overall vascular anatomy in the serratus anterior/rib composite flap and observe the vascular networks that were distributed from the intercostal arteries to the ribs. The chest wall was removed by making incisions from the third rib on the cranial side, the ninth rib on the caudal side, anteriorly on the lateral side of the sternum, and posteriorly on the dorsal side of the serratus anterior branch of the thoracodorsal artery. Then, the serratus anterior branch of the thoracodorsal artery was cannulated; a dyeing solution was injected and the leakage points were ligated. Each rib was fixed to an acrylic plate, and 30 ml of Mercox II was injected into the serratus anterior branch of the thoracodorsal artery. After the resin cured, the specimen was placed in 4% NaOH aqueous solution for 48 hours to erode the soft tissues. Then, the specimen was washed with running water for 48 hours and dried at 45°C for 24 hours in a heating cabinet (IC43; Yamato Scientific Co., Ltd., Tokyo, Japan). After the cast dried, blood vessels in the subcutaneous layer of the skin and capillaries in the muscle fibers were carefully removed microscopically, and a cast comprising the area ranging from the serratus anterior branch of the thoracodorsal artery to the intercostal arteries was manufactured.

3. Results

Blood Circulation in Serratus Anterior Rib Flap

Of the 14 sides of 7 cadavers, macroscopic autopsy was performed on 8 sides, which showed a good injection of resin. The remaining 6 sides were excluded due to poor injection of resin. Of 24 slip arteries of the serratus anterior muscle, which are attached to the sixth, seventh, and eighth ribs, dissection of the axial route was successful for 23 (Fig. 2). For 1 slip artery attached to the eighth rib, the path was unclear; therefore, dissection was impossible. Of the 23 slip arteries subjected to dissection, the common slip artery was present in 22 and the proper slip artery was present in 1. The distance between the interconnecting vessels and the anterior margin of the attachment site of the serratus anterior muscle to the ribs was 3.5–7.5 cm at the sixth rib (mean: 5.0 cm), 2.5–7 cm at the seventh rib (mean: 4.4 cm), and 2–5.5 cm at the eighth rib (mean: 4.1 cm). The diameters of the interconnecting vessels were as follows: 0.2–0.9 mm (mean: 0.5 mm) for the sixth interconnecting vessel, 0.4–0.8 mm (mean: 0.5 mm) for the seventh interconnecting vessel, and 0.3–0.9 mm (mean: 0.6 mm) for the eighth interconnecting vessel (Table 1).

Three-dimensional CT angiography

Several slip arteries branched from the serratus anterior branch of the thoracodorsal artery, and a large number of intramuscular capillaries were depicted on angiography; the orientation of the slip arteries coincided with the direction of the serratus anterior muscle fibers (Fig. 3). The contrast medium reached the sixth to the eighth intercostal arteries, and the resulting images confirmed that the periphery of the slip arteries flowed directly into the intercostal arteries through the interconnecting vessels (Fig. 4).

Assessment of the interconnecting vessels was performed for cases that showed continuity in the contrast-enhanced area between the serratus anterior branch of the thoracodorsal artery and the intercostal arteries in the sixth, seventh, and eighth ribs. Of the 60 sides of 30 cadavers, the number of cases involving each rib studied were as follows: 25 sides for the sixth rib, 27 sides for the seventh rib, and 15 sides for the eighth rib. The remaining cases were excluded due to poor contrast in contrast enhanced CT images. The distances between the interconnecting vessels and areas of the costochondral junction were as follows: 5.8–9.4 cm (mean: 7.3 cm) for the sixth rib, 4.7–10.7 cm (mean: 7.4 cm) for the seventh rib, and 4.7–11.9 cm (mean: 7.6 cm) for the eighth rib (Table 1).

Anatomical corrosion casting findings

The entire vascular anatomy in serratus anterior/rib composite flaps was successfully visualized, including multiple slip arteries branching from the serratus anterior branch of the thoracodorsal artery and capillaries branching from the intercostal arteries and branching around the ribs (Fig. 5). However, removing capillaries from inside muscle fibers while preserving the continuity of blood vessels around the interconnecting vessels was technically challenging, and complete reproduction of the axial route was difficult with the vascular cast. In the ribs, several blood vessels branching from the intercostal arteries to the surface of the ribs and toward the intercostal muscles had paths that travelled mutually as periosteal capillaries. In addition, several blood vessels branching from intercostal arteries connected with the capillary of the adjacent rib surface (Fig. 6). Conversely, on the inner side of the rib cage, there were only a few relatively thick blood vessels branching from the intercostal arteries. However, their paths could not be identified (Fig. 7).

4. Clinical findings

Based on our anatomical study, the interconnecting vessels in the sixth rib and eighth rib were identified clinically. A serratus anterior/rib composite flap including those interconnecting vessels was elevated.

Elevation of the flap

Preservation of the periosteal route and axial route is the most important aspect of elevating serratus anterior/rib composite flaps. The serratus anterior branch of the thoracodorsal artery branches into two types of slip arteries: the proper slip artery traveling through the middle of the serratus anterior muscle and the common slip artery traveling between slips of the serratus anterior muscles. The common slip artery further branches into two adjacent slip arteries.[19, 20] In our study, either slip artery intersected with the interconnecting vessels at the dorsal side of the inferior margin of the serratus anterior muscle. Therefore, to accurately elevate a bone flap including slip arteries and interconnecting vessels, muscle dissection should not be performed between the slips of the serratus anterior muscle; instead, dissection with the next slip of the serratus anterior muscle that needs harvesting should be performed. Next, the muscle should be turned over to identify the interconnecting vessels that pass through the intercostal muscles near the posterior margin of the attachment site of the serratus anterior muscle to the ribs (Fig. 8). Then, the internal and external intercostal muscles should be cut off while avoiding injury to the interconnecting vessels. Finally, depending on the amount of bone flap required, osteotomy of the ribs should be performed from the anterior margin of the attachment site of the serratus anterior muscle to the ribs, and a bone flap including the intercostal arteries should be elevated

(Fig. 9).

After flap elevation was accomplished, indocyanine green fluorescence angiography was performed to confirm blood flow. First, the slip arteries were contrast-enhanced. Then, the interconnecting vessel and the intercostal arteries were contrast-enhanced. In addition, multiple branches flowing from the intercostal arteries to the costal periosteum were contrast-enhanced (Video 1). Furthermore, the intercostal arteries were preserved and osteotomy was performed at two different sites. Good bleeding was confirmed in all bone stumps (Video 2).

5. Discussion

Several previous reports have analyzed the vascular anatomy in serratus anterior/rib composite flaps. Richards et al. and Bruck, Bier, & Kistler injected a dye into the thoracodorsal artery and reported that there was continuity between the serratus anterior branch and the intercostal arteries via the periosteal vessels.[1, 2] In a radiological study, Sabri et al. and Hui et al. mentioned the presence of a vascular network between the serratus anterior muscle and the intercostal arteries.[11, 17] Additionally, during microscopic examination, Hui et al. discovered the existence of communicating vascular channels at sites located along the anterior axillary line.[11] Those reports were mainly based on two-dimensional contrast imaging using plain radiography. Although several reports mentioned the existence of the vascular network, it was not visualized. In 2007, Werner et al. accomplished vascular corrosion casting of serratus anterior/rib composite flaps; although they performed three-dimensional visualization of the vascular network from the serratus anterior muscle to the ribs, mainly the periosteum, there was no mention of the axial route that we proposed in the present study.[18]

Serratus anterior and rib composite flap with two vascular routes

Previously, blood flowing from the muscle to the ribs in serratus anterior/rib composite flaps was believed to follow the periosteal route. However, the current study revealed the existence of an axial route that allows for slip arteries to flow directly to the intercostal arteries through interconnecting vessels. The importance of the axial route lies in the existence and localization of interconnecting vessels, and the results of cadaver dissection and CT analysis showed that in the sixth, seventh, and eighth ribs, the interconnecting vessels were located at a mean distance of 4.5 cm from the anterior margin of the attachment site of the serratus anterior muscle and at a mean distance of 7.4 cm from the costochondral junction. This coincided with the posterior margin of the attachment sites of the serratus anterior muscle to the ribs. In other words, this may have been why the areas surrounding the attachment sites of the serratus anterior muscle to the ribs were previously reported to have the most developed vascular network. In addition, the interconnecting vessels had a diameter between 0.5 and 0.6 mm, which could be confirmed easily with the naked eye.

Vascular anatomy of the ribs

Using vascular corrosion casting, we found multiple branches flowing from the intercostal arteries to the surface of the ribs. These findings confirmed the presence of a capillary network that seemed to be the periosteal blood circulation, which combined with the findings from intraoperative bleeding proved that sufficient blood flow was maintained, even in the presence of periosteal blood circulation without a nutrient branch of the intercostal artery. Furthermore, in 2001, Chang et al. described a method of harvesting rib bone samples[21] using a subperiosteal approach in which the intercostal arteries and veins were preserved to prevent pleural injury; however, the results of our study indicated that the intercostal arteries may need to be included to maintain good blood flow in the ribs.

There were some limitations to this study. First, macroscopic autopsy and contrast-enhanced CT showed that the resin and contrast agent did not reach the intercostal arteries in more than half of the studied cases. This may have been due to the condition of the fixed cadavers, which allowed for the formation of blood clots inside blood vessels, resulting in an obstruction of arteries peripheral to the slip arteries. Second, the assessments performed during our study were performed only for the arterial system and not for the venous system. Therefore, in the future, assessments of the venous system should be performed as part of a comprehensive evaluation of bone flap hemodynamics.

6. Conclusion

We found that the axial route via the interconnecting vessels is important for blood circulation in serratus anterior/rib composite flaps. When harvesting serratus anterior/rib composite flaps, adding the axial route to the periosteal route allows for harvesting graft tissues with better blood flow. Furthermore, better blood flow makes it possible to dissect the ribs at multiple locations, allowing for reconstruction with more complex shapes based on each patient’s unique anatomy.

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Figure legends

Figure 1: Schema of the serratus anterior and rib composite flap. One serratus anterior muscle (slip) attaches to one rib. There are two types of slip arteries in the serratus anterior muscle. The common slip artery branches into two slip arteries for the two adjacent slips, and the proper slip artery travels inside the serratus anterior muscle as a single slip artery.

Figure 2: Each slip artery traveling inside the serratus anterior muscle was dissected from the serratus anterior branch of the thoracodorsal artery. In all cases, the peripheral branches of the slip arteries joined the intercostal arteries directly through the interconnecting vessels (▶) (axial route).

Figure 3: Three-dimensional contrast-enhanced computed tomography image of the lateral face. The serratus anterior branch of the thoracodorsal artery was contrast-enhanced up to the intercostal arteries. The serratus anterior branch of the thoracodorsal artery branched into multiple slip arteries (▶). The network of capillaries inside the serratus anterior muscle is also depicted.

Figure 4: Three-dimensional contrast-enhanced computed tomography showing a tangential section of the chest wall. The peripheral extremities of the slip arteries flow directly into the intercostal artery through interconnecting vessels.

Figure 5: Vascular corrosion casting of a serratus anterior and rib composite flap. The capillaries

inside the fibers of the serratus anterior muscle were removed. The common slip artery was found to travel between the ribs and then branch out, and the proper slip artery traveled to the center of the ribs.

Figure 6: Vascular cast of the outer view of the rib cage. Capillaries were distributed in the surface of the ribs and the intercostal space, and the capillaries crossed each other. Many capillaries comprising the periosteal blood circulation were found on the surface of the ribs. Several blood vessels (▶) branching from the intercostal arteries connected with the capillary of the adjacent ribs surface.

Figure 7: Vascular cast of the inner side of the rib cage. The findings confirmed the presence of a large number of capillaries branching from the intercostal arteries. Most capillaries were distributed in the anterior surface of the ribs, and the distribution of capillaries was poorer on the underside of the ribs than on the anterior surface.

Figure 8: Intraoperative findings. The serratus anterior muscle should be turned over to identify the interconnecting vessels penetrating the intercostal muscles. The slip arteries traveled inside the serratus anterior muscle; therefore, they could not be identified.

Figure 9: Site of incision of the serratus anterior muscle during elevation of a bone flap using the sixth and eighth ribs. An incision (*) was made to the next slip of the serratus anterior muscle that needs harvesting. Next the muscle was turned over and intercostal perforators were

identified. An incision (→) was made to the intercostal muscles while precautions were taken to avoid injuring the intercostal perforators. Bone flaps, including the intercostal arteries were harvested.

Video 1: Indocyanine green (ICG) angiography on a serratus anterior rib graft. The contrast agent enters the slip arteries, runs through the interconnecting vessels, and reaches the intercostal arteries.

Video 2: Blood flow findings after osteotomy. The intercostal arteries were preserved and osteotomy was performed at two locations on the ribs. Good bleeding was confirmed in the bone stumps of both extremities.