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A functional periorbital subunit allograft: Vascular, anatomic, and technical considerations for future subunit facial transplantation

David W. Mathes [a,*], James A. Edwards [a], Yoshimi Anzai [b], Peter C. Neligan [a]

[a] *Division of Plastic Surgery, University of Washington Medical Center, Seattle, WA, USA*
[b] *Department of Radiology, University of Washington Medical Center, Seattle, WA, USA*

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Summary *Background:* Injury to the face can result in the loss of critical specialized structures (the eyelids, lips, ears and nose). Vascularized composite allotransplantation (VCA) allows the surgeon to replace exactly what has been lost. The success of the clinical face transplants suggests the possibility of transplanting specialized units of the face. In this study we explore the neurovascular anatomy and technical specifics for harvest of a functional composite eyelid subunit flap.
Methods: 12 fresh cadaver heads were studied, each yielding two flaps ($N = 24$). The facial (FA) and superficial temporal arteries (STA) were cannulated and injected with a gelatin/acrylic dye mixture. 6 cadaver heads were evaluated via high-resolution three-dimensional CT scans with contrast.
Results: The dye injected into the STA uniformly stained the tissue of the eyelid/periorbital subunit. Injection into the FA resulted in staining of the skin and soft tissues in the medial canthal region and superior eyelid skin in 66% of specimens. CT scan studies confirm our findings with injection into the STA resulting in contrast infiltration of the palpebral arterial arcades in all cases. Injection of the FA resulted in contrast infiltration of the palpebral arterial arcades in 2 of 3 cases.
Conclusions: Based this study, a periorbital flap can be based on the STA. Motor innervation of the flap is via the zygomatic and buccal branches of the facial nerve with sensory innervation

* Corresponding author. University of Washington Medical Center, 1959 NE Pacific Street, Box 356410, Seattle, WA 98115, USA. Tel.: +1 (206) 543 5516; fax: +1 (206) 543 8136.
E-mail address: dwmathes@uw.edu (D.W. Mathes).

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via the infraorbital, supraorbital and supratrochlear nerves. FA could be used, but its ability to perfuse the entire flap was inconsistent.
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Introduction

The emerging field of reconstructive transplantation offers the opportunity to restore damaged or missing tissue with the exact structures lost. While structures such as the eyelid or the lip can be reconstructed with conventional techniques, these reconstructions fail to replicate true form and function. A vascularized composite allograft (VCA) can serve as an ideal replacement for missing tissues without any donor site issues. The clinical application of VCA has seen remarkable progress with over 54 hand transplants in 41 patients performed worldwide[1–3] and more recently reports of success in over 24 facial transplants.[4–10] The clinical cases of facial transplant have largely focused on the replacement of large regions of the face with excellent flap survival.[11,12] The majority of clinical research and discussion has centered on "whole" face transplantation.[13–18] However, our clinical experience in the field of reconstructive surgery indicates that there will also be a need for replacement of individual functional aesthetic subunits (such as eyelids, lips, ears and nose). It is unclear from both our conventional clinical experience and the current literature if it will be technically feasible to harvest and transplant these individual subunits.

This study examines the anatomy, vascular supply and technical feasibility of harvesting a functional periorbital subunit flap. We defined the following aims for this investigation. 1. To define an anatomic basis for a functional periorbital subunit flap including arterial and venous flow, and motor and sensory innervation.

2. To harvest the flap in a consistent and reproducible fashion, within a reasonable time limit.

Methods

Dye injection studies

12 fresh cadaver heads were used and each specimen yielded two separate flaps ($N = 24$). Each head was prepared by flushing the arterial systems (via the common carotid artery) with cold water until clear fluid was seen flowing from the internal jugular vein. Dissection was performed under 2.5× loupe magnification.

The dissection started by isolating the Superficial Temporal Artery (STA) in the pre-auricular region and cannulated it with a 20-gauge angiocath. Next, a transverse incision was made along the inferior mandibular border, half the distance between the gonial angle and the pogonion, immediately anterior to the anterior border of the Masseter and the facial artery was isolated and cannulated with a 20-gauge angiocath. The proximal arterial stump was ligated to prevent backflow. The intraoral opening of Stensen's duct was identified and cannulated with either a 20 or 22-gauge catheter.

Concurrently, we prepared our arterial injection medium (a mixture of 14 g of gelatin with 200 mLs of water and 5 mLs of one of three colored dyes: Blue Acrylic Dye, Red Acrylic Dye, and Green Acrylic Dye). A separate gelatin/dye mixture was also made according to the ratios mentioned above, using 5 mLs of India Ink Dye for retrograde injection into the Parotid duct.

The arterial systems were injected, each with a corresponding dye: blue for the facial artery, red for the superficial temporal artery, and green dye for the internal carotid artery. Upon injection, there was a cutaneous blush corresponding with the artery injected and dye used. The Parotid duct was injected with the India Ink mixture in a retrograde fashion. The gelatin/dye mixtures were then allowed to set for an hour to facilitate dissection.

The flap elevation proceeded by dissecting along the FA and STA in a proximal to distal fashion. For the periorbital dissection, we designed an ellipse of skin that included the eyelids, medial and lateral canthal areas, and the inferior periorbital skin up to the eyelid/cheek margin and the superior periorbital skin up to the eyelid/brow margin. This incision encompassed the entirety of the peri-orbital subunit. The initial incision was carried into the superficial subcutaneous fat to establish the cutaneous boundaries of the flap.

Superior flap dissection was then done by elevating a superior skin flap for 3–4 cm and then transitioning deep to a subperiosteal plane, leaving a cuff of frontalis with the flap. The subperiosteal dissection facilitated easier visualization of the supraorbital and supratrochlear nerves and allowed them to be transected and included with the flap with the maximal length possible. As the superior orbital rim is approached, the orbital septum is visualized and reflected with the flap. Directly adjacent to the few millimeters of reflected septum is the Levator Palpebrae Superioris muscle. A large cuff of Levator muscle was included with the flap and the dissection completed by incising along the transverse length of the Superior Conjunctival Fornix. Care is taken at the superolateral portion of the conjunctival incision to dissect and include both lobes of the lacrimal gland, which are divided by the Levator aponeurosis.

The medial border of the flap was raised by incising along the border of the periorbital and lateral nasal subunit directly down to periosteum and proceeded in a subperiosteal plane from medial to lateral. The medial canthal tendon was lysed, being careful to protect the branches of the palpebral artery, which are located directly subjacent to the tendon. Superomedially, the trochlea is lysed and intraorbital dissection is performed in order to identify and ligate the third division of the Ophthalmic artery, which in a majority of specimens gives off the main Palpebral arterial trunk, Supratrochlear artery and the Dorsal Nasal artery. Inferomedially, the lacrimal excretory apparatus is divided as the common canaliculus enters the bone between the anterior and posterior lacrimal crests.

The lateral flap dissection begins by elevating a skin flap from lateral to medial through the previous pre-auricular incision, proceeding as far superiorly as the previous periorbital incision, effectively joining the dissection planes and making one large cutaneous, midface/cheek flap. With the facial skin flap reflected, dissection then proceeds superficial to deep just anterior and inferior to the tragus until the Parotid fascia is encountered. For the purposes of this study, the parotid duct was injected in a retrograde fashion with the India Ink/gelatin preparation in order to stain the glandular parenchyma and facilitate visualization of the facial nerve along its' intraglandular course. A superficial parotidectomy was then performed. The major trunks and then the branches of the facial nerve are then identified, isolated and dissected along their course within the substance of the parotid gland. In order to facilitate dissection and include the vasa nervorum coming from the Transverse Facial Artery (TFA) as it travels within the parenchyma of the parotid, the deep portion of the gland is included with the flap. Dissection then proceeds deep to the facial nerve branches, keeping the zygomatic and the buccal branches with the flap where possible. As the inferolateral orbital rim is approached, transition is made to the subperiosteal plane, keeping the facial nerve branches with the flap. This is done until the arcus marginalis is encountered. The arcus is then released, and the capsulopalpebral fascia is then divided as far posteriorly as possible. The inferior dissection is completed by incising along the transverse length of the inferior conjunctival fornix and meeting the margins of division of the superior portion of the flap.

Superolaterally, the STA is reflected with the flap and dissection proceeds in the same plane as the facial nerve dissection until the lateral orbital rim is encountered. In this plane, one is deep to the orbicularis oculi muscle and can easily transition to a subperiosteal plane. Dissection is completed by elevating the lateral orbital fascial condensation with the flap and then lysing the lateral canthus off Whitnall's tubercle.

Radiographic studies

6 fresh cadaver heads were prepared via the same arterial flushing technique and either the STA or the FA was identified and cannulated with a 20-gauge angiocath. The proximal arterial stump was suture ligated to prevent any backflow of contrast.

The cadaver heads then underwent Computed Tomographic (CT) Angiography on 64 channel multi-detector row computed tomography (Lightspeed CT, GE Healthcare). Continuous 0.625 mm axial slices were obtained from vertex to the mandible following a single injection of 5 cc of Iohexol contrast (Omnipaque 350®) into the selected vascular system. The following parameters were used to obtain CT angiography of cadaveric head; 140 kvp, 450 mA, 0.5 s axial rotation, and 20 cm field of view, and 0.531: 1 pitch. In order to study the pedicle of interest, each head had only a single pedicle dissected unilaterally. Post-scan three-dimensional volume rendering images were obtained in the workstation, in addition to maximum intensity projection images in axial, coronal, and sagittal views.

Results

Dye injection studies

24 separate periorbital subunit flaps were harvested. In all cases, injection of the STA resulted in staining of the periorbital region including the eyelids and conjunctiva (Figure 1). Injection of the FA pedicle failed to result in staining in the periorbital region in 8 of the 24 flaps. In 6 of these flaps it was noted on dissection that the facial artery either transitioned to the angular artery but then did not continue to the medial canthal region (Figure 2) or ended at the branch point of the superior labial artery. In 2 of the flaps it was noted that the angular artery was present and could be found in the medial canthal region but was diminutive and resulted only in minor cutaneous staining of the medial periorbital skin. In the remaining 16 flaps, the facial/angular artery seemed to form an anastomotic network in the medial canthal area with the palpebral arterial system.

In all flaps the STA was successfully harvested with the flap. The FA was successfully harvested with the flap in those specimens where the angular artery joined into the medial canthal arterial network. The typical appearance of a flap after harvest is shown in Figure 3.

Of note, there was significant variation in arterial anatomy during flap dissection. In our series it was noted that while all the flaps had a true transverse facial artery (TFA), there was significant difference in the branching pattern or vessel caliber that seemed to be inversely

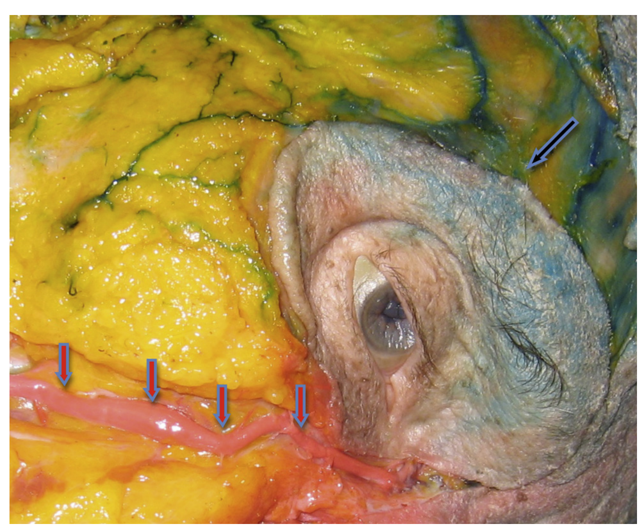

Figure 1 Blue staining of the cutaneous portion of the periorbital subunit is shown (black arrow). The smaller red arrows show the facial/angular artery as it transitions superiorly to the medial orbit.

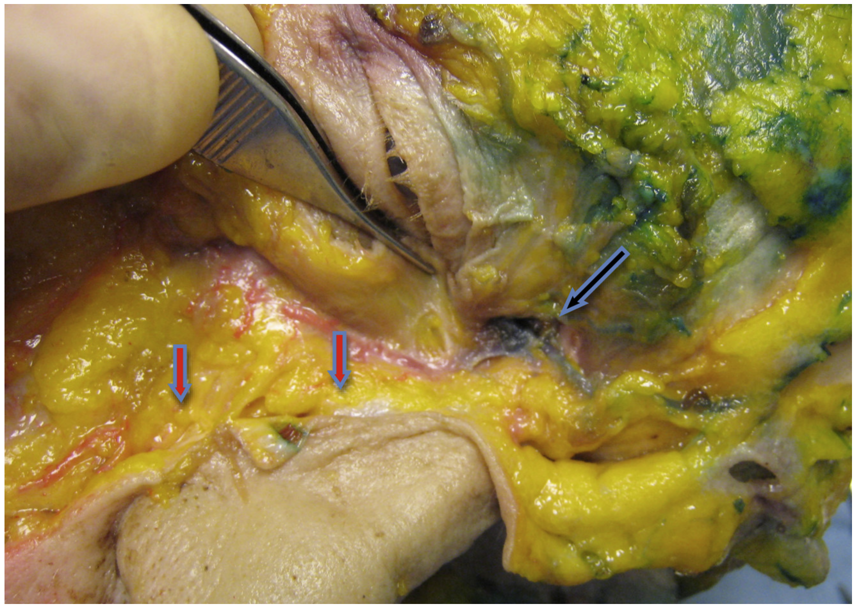

Figure 2 The medial orbital vessels are stained blue (black arrow) suggesting perfusion via the Superficial Temporal Artery. This specimen also had absence of the angular artery (red arrows).

proportional to the presence or caliber of the facial/ angular artery. In 5 of the 6 specimens where the angular artery was either absent or didn't anastomose with the medial canthal arterial network, the TFA was noted to be larger in caliber compared with the other specimens. In the remaining specimen that had an absent angular artery the TFA had two large branches (superior and inferior). It was also noted that the TFA appeared to be larger than average in the 2 specimens where the angular artery was noted to be diminuitive (where minor cutaneous staining was noted).

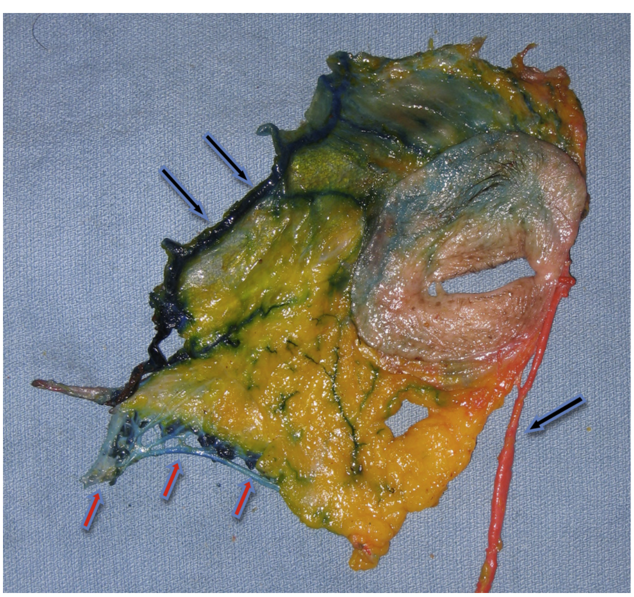

Figure 3 Typical appearance of a harvested flap. The candidate vascular pedicles are shown: Facial Artery (single black arrow) and Superficial Temporal Artery (double black arrow). The red arrows show the facial nerve branches that were included with the flap.

Average time of flap harvest was 2.67 h ($\pm$ 1.3 h). As expected, there was a "learning curve" in terms of flap dissection with earlier dissections taking significantly longer. The average of the last 6 dissections was 2.2 h ($\pm$ 0.4 h). The portion of the harvest that required the longest time to accomplish was dissection of the facial nerve branches. This on average required 1.34 ($\pm$ 0.83 h).

Radiographic studies

The STA was injected with contrast in 3 of our cadaveric specimens. A typical result from this study is shown in Figure 4. In all three specimens, the STA gave off both a frontal and a parietal branch. These specimens all showed that the frontal branch of the STA gives off an arcade of supraorbital branches that supply the periorbital region. The arterial distribution can be seen to supply the superior eyelid. The branches also form an anastomotic network with the ophthalmic arterial system and the superior and inferior palpebral arcades.

The remaining 3 cadaver specimens had the FA injected. Two of the specimens showed enhancement of the angular artery which traveled superomedially to anastomose with the ophthalmic arterial network near the medial canthus. In these two specimens there was enhancement of the palpebral arterial arcades. In the third specimen, there was enhancement of the angular artery, which reached the medial canthal area, where it anastomosed with the ophthalmic arterial network, but there was no enhancement of the palpebral arterial arcades (Figure 5).

Discussion

Severe injury to the face can result in the loss of critical specialized structures such as the eyelids, lips, ears and nose. Current reconstructive techniques can provide restoration of these complex structures but requires

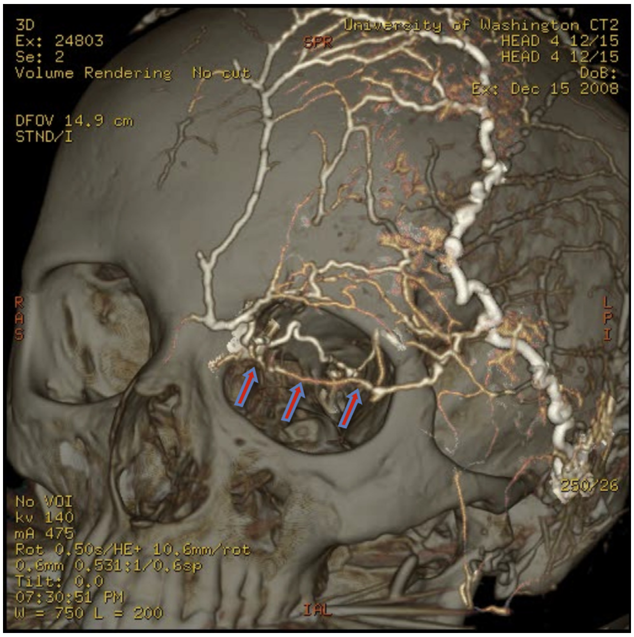

Figure 4 Typical CT angiogram showing injection of the left Superficial Temporal Artery with enhancement evident of the Superior Palpebral Artery (red arrows).

multiple surgical procedures to achieve an acceptable result. In most cases, it is impossible to reconstruct the functional aspects of these structures. In addition, these reconstructive procedures produce a donor site that can add additional morbidity.

To date there have been greater than twenty-four successful facial transplants. These transplants suggest the future possibility for the transplantation of individual specialized units of the face such as the eyelid. However,

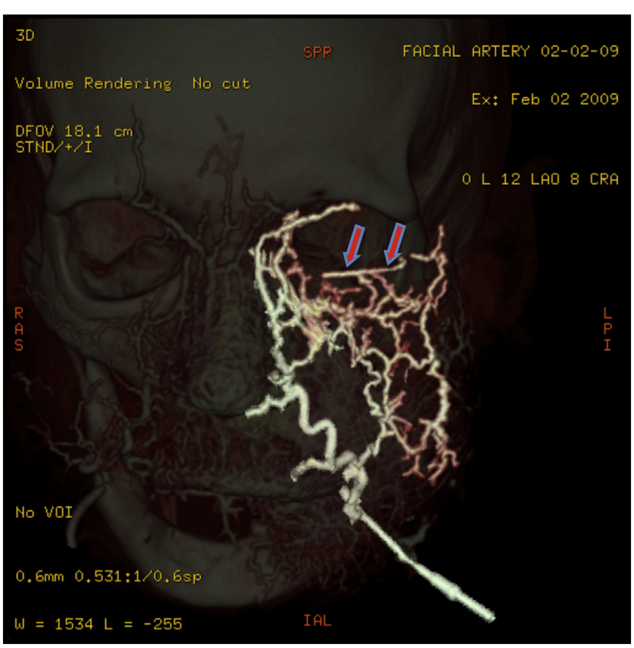

Figure 5 CT angiogram showing injection of the right Facial Artery. There is enhancement of the inferior palpebral artery (red arrows).

very few of these transplants have included of any portion of the functional periorbital subunit within the facial allograft.[7,11] Dr. Siemionow's group included bilateral lower eyelids in a LeFort III midfacial soft tissue composite construct.[7,11] While sensory reinnervation has been noted to be near normal in this patient, the function of the lower eyelids was noted to be "imperfect" and the ultimate functional outcome remains uncertain.[7] Dr. Lantieri's group in France performed a facial transplant that reconstructed the upper 2/3rds of the face (including eyelids) in addition to undergoing a bilateral hand transplant.[7,8,12,19] The patient expired almost two months post-operatively without any report of functional recovery of the eyelids.

In this study we sought to explore the neurovascular anatomy and technical specifics for harvest of a functional composite eyelid flap as a single, vascularized facial subunit. There have been a number of studies that have addressed techniques for harvest of a composite facial transplant in a cadaveric model.[14—18] These studies address the harvest of a total or near total facial construct but to our knowledge there has been only one previous report in the literature that describes harvest of a functional periorbital subunit flap.[20] Our study, however, includes additional vascular information via dynamic perfusion of the tissue via CT angiography. Our principal goals for this study were to define the anatomic specifics of a functional periorbital subunit flap and to elucidate the technical details required for harvest. As outlined above, the requisite anatomic structures required to establish a functional periorbital flap can be identified and dissected with relative ease. The most challenging part of the technique is dissection of the branches of the facial nerve. In previous studies it has been demonstrated that motor innervation to the Orbicularis Oculi is most likely via the Zygomatic (extracanthal portion) and Buccal (intercanthal portion) branches of the facial nerve.[21—24] Because of this we included as many of the smaller branches of these nerves as possible with the flap.

Our results demonstrate that, in unlike the previous paper on this topic, perfusion to the periorbital subunit flap could be established reliably via the Superficial Temporal Artery in all cases.[20] Perfusion via the Facial Artery was not as reliable, likely due to the inconsistent presence of the Angular Artery branch. In 33% (8 of 24) of our dye injection specimens and 33% (1 of 3) of our CT angiogram specimens there was either no evidence that the Facial Artery gave off any tributaries to the periorbital region or the artery was too diminutive to provide enough perfusion to supply the flap. The Superficial Temporal Artery represents the best target vessel for revascularization.

Given that there is little experience with functional replacement of the eyelids or the supporting adnexal structures via allotransplantation, the application of the results of this study to a clinical model is a transition that requires several considerations. Firstly, the vascular studies done here demonstrate that anatomy is not fixed and variation is the rule and not the exception. While the STA and FA are both possible target vessels for revascularization, neither can be assumed to be adequate and an intraoperative study would be required to confirm the presence and flow volume prior to flap harvest. This could be done via selective angiography or Doppler imaging.

The ultimate function of the periorbital flap is based on recovery of voluntary eyelid opening (ideally with recovery of reflex blinking as well). This requires partial presence of the recipient levator mechanism, as the greatest portion of eyelid opening is done via the levator mechanism of the upper eyelid with a smaller contribution by the sympathetically innervated Müller's muscle.[25,26] The aponeurotic portion of the levator mechanism is harvested with our flap and would be attached to the host's native levator mechanism to generate elevation of the upper eyelid. Analogously, in the lower eyelid, the Capsulopalpebral fascia (CPF) would theoretically be attached to the remainder of the host CPF or secured to the Inferior Oblique muscle, which serves as the normal origin of the CPF.[27]

The lacrimal gland is harvested with the flap but is deinervated during the harvest. Normal glandular innervation is via the ophthalmic division of the Trigeminal Nerve and it is unclear if reinervation would occur.[23,28] Vascular compromise of the lacrimal gland is also possible due to the division of the ophthalmic artery,[29–31] perfusion would likely be maintained via retrograde flow through the Müller vascular network.[31] The flap can be harvested without inclusion of the lacrimal gland for those cases where the recipient gland is present. In regard to lacrimal drainage, the common canaliculus was transected flush as it passed between the anterior and posterior lacrimal crests in our dissections. Therefore, a dacrocystorhinostomy would need to be performed to re-establish a nasolacrimal conduit.[32–34]

The central advantage to individual subunit allotransplantation would be that it allows for minimal resection of normal adjacent recipient tissue. In more than one case normal tissue has been resected in order to accommodate the allotransplant. Individual subunit transplantation effectively allows one to tailor the flap to exactly those tissues that are missing, without sacrificing autologous options and without creating a larger donor defect. The results of this study demonstrate that it is possible to harvest a functional periorbital subunit flap reliably reproducibly and within a reasonable amount of time. In addition, this study advances the possibility of transplanting individual facial subunits.

Approval

This work was approved by the University of Washington Institutional Review Board (Use of Biological Specimens Review Determination Form, HSD No. 35280).

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Conflict of interest

The authors have no conflicts or interests, financial or otherwise, to disclose in relation to the content of this article.

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