International Microsurgery Journal

ORIGINAL

Chimeric Radial Forearm Flap With Pronator Quadratus Muscle for Facial Reanimation: An Anatomical Feasibility Study

Chieh-Han John Tzou, MD, PhD[1,2*]; Johannes Steinbacher, MD[1]; Stefan Meng, MD[3,4]; Aaron Metz, MD[1]; Sabine Oliva, MD[1]; Wolfgang J. Weninger, MD[3]; Andrés Rodriguez-Lorenzo, MD, PhD[5]

[1]Plastic and Reconstructive Surgery, Department of Surgery, Hospital of Divine Savior, Vienna, Austria
[2]TZOU MEDICAL., Vienna, Austria
[3]Division of Anatomy, Center for Anatomy and Cell Biology, Medical University of Vienna, Vienna, Austria
[4]Department of Radiology, Hanusch Hospital, Vienna, Austria
[5]Department of Surgical Sciences, Plastic and Maxillofacial Surgery, Uppsala University, Uppsala, Sweden

ABSTRACT

Objective: A novel surgical technique to reanimate a paralyzed face, utilizing the functional transplantation of the pronator quadratus muscle (PQM) in combination with a radial forearm flap (RFF) to cover a soft-tissue defect, was recently described. Although it is known that this muscle is supplied by the interosseous artery, a flap combining the radial artery has shown sufficient vascularization of this muscle as well. The PQM is generally poorly described in the literature, and there is insufficient information regarding its anatomical landmarks and vascular supply. The aim of this study was to specify the anatomical features of the PQM and provide a description of its vascularization by the radial artery using fresh cadavers.

Methods: The study involved the dissection of 20 pronator quadratus muscles from 10 fresh cadavers. To visualize the muscle branches within the PQM, the radial artery was injected with a methylene blue solution. Measurements were taken for the number of muscle branches, innervation, length, weight, and width of the PQM. Additionally, anatomic landmarks based on the radius bone were documented.

Results: There were up to four muscle branches of the radial artery supplying the PQM. The average muscle weight was 8 ± 3 g, with a mean length of 50 mm and a mean width of 45 mm distally and 48 mm proximally. On the radius, the proximal border of the PQM averaged 169 ± 21 mm from the radial head, corresponding to 73 ± 3% of the radial bone length, while the distal border was at an average of 218 ± 24 mm (95 ± 3%). On the ulnar aspect, the proximal and distal borders of the PQM measured on average at 190 ± 18 mm (74 ± 4%) from the olecranon and 244 ± 23 mm (96 ± 3%), respectively.

Conclusion: There are up to four muscle branches of the radial artery, each under 0.5 mm in diameter, that arise from the radial artery in the area of the PQM origin and insertion. These branches should provide a constant blood supply to the PQM when it is raised with a free radial forearm flap as a chimeric flap.

INTRODUCTION

Facial paralysis patients experience facial asymmetry, impaired emotional expression, and difficulties with activities such as eating, drinking, speaking, and communicating [1]. Nowadays, functional reconstruction methods offer established techniques for reanimating the faces of patients with irreversible facial palsy [2–11]. In cases involving the simultaneous resection of skin, muscle, and the facial nerve, the challenge lies in restoring facial function while achieving skin closure. A case report has described the use of a chimeric radial forearm flap with innervated pronator quadratus muscle (PQM), achieving satisfactory results [12]. This surgical technique reanimated a partially paralyzed face by transplanting the PQM functionally in combination with a radial forearm flap (RFF) to cover the soft-tissue defect [12].

However, a detailed description of this method regarding the PQM's blood supply, when combined with the radial forearm flap, has not been previously reported. In this study, the authors aim to revisit the anatomical landmarks of this flap and provide a comprehensive examination of the vascular anatomy based on the radial forearm artery, which is used for free functioning muscle transfer in facial reanimation.

MATERIALS AND METHODS

Twenty arms were meticulously dissected in ten fresh adult cadavers (seven males and three females) at the Center of Anatomy, Medical University of Vienna, Austria, to study the diameter, length, and caliber of the radial artery branches leading into the PQM and their relationship to bony anatomical landmarks. Additionally, the weight and size of the PQM were assessed.

The dissection of the PQM flap followed the standard procedure for the radial forearm flap. Care was taken during the dissection of the radial artery in the distal quarter along the radius. When all flexor tendons were retracted ulnarly, the arterial muscle branches became visible, originating from the radial artery and running in an ulnar direction into the PQM muscle. The interosseous nerve could be dissected at the proximal border of the PQM, as close to its origin as possible, and then resected around the midpoint of the radius. After exposing the PQM branches and the interosseous nerve, the PQM muscle was gently elevated from the ulna and radius using a raspatory. The PQM blood supply was examined under 3x loupe magnification after injecting a methylene blue solution (C.I.52015, LabChem Röttinger, Dinslaken, Germany) into the origin of the

Table 1. Proximal Borders of the PQM in Correlation With the Lengths of the Radial and Ulnar Bones[1]

Proximal borders of PQM	n	Mean (SD), mm	Percentage of the total length of both bones (SD), %	Minimum, %[2]	Maximum, %[3]
From the radial head	20	168 (20.5)	73 (3)	68	80
From the olecranon	20	190 (18.3)	74 (4)	68	83

[1]The proximal borders of the pronator quadratus muscle exhibit a correlation with the lengths of the radial and ulnar bones. These borders are situated within the range of 68% to 83% of the total length of both bones.
[2]The minimum length of the proximal PQM borders in correlation with the lengths of the radial and ulnar bones is expressed as a percentage.
[3]The maximum length of the proximal PQM borders in correlation with the lengths of the radial and ulnar bones is expressed as a percentage.
Abbreviations: PQM, pronator quadratus muscle; SD, standard deviation.

radial artery. All measurements were taken from proximal to distal. On the radial aspect, measurements started from the radial head, while on the ulnar aspect, measurements began from the olecranon.

This study was conducted in accordance with the local ethics regulations of the Center of Anatomy and Cell Biology, Medical University of Vienna, Austria.

RESULTS

The PQM is predominantly a trapezoid-shaped muscle, with an average proximal width of 48 ± 10 mm, a distal width of 45 ± 9 mm, and an overall length of 50 ± 9 mm. The muscle's weight varied from 3.2 g to 14.6 g.

Among the PQMs (n = 20), 40% exhibited equal proximal and distal widths, 50% had a wider proximal width than distal, and only 10% (n = 2) of all muscles were wider at the distal end than the proximal.

The radial bone had an average length of 230 ± 24 mm. On the radial side, the proximal borders of the PQM were found, on average, at 169 ± 21 mm from the radial head, accounting for 73 ± 3% of the radial bone's length, while the distal border was at 218 ± 24 mm (95 ± 3%).

On the ulnar aspect, the proximal and distal borders of the PQM were measured at 190 ± 18 mm (74 ± 4%) from the olecranon and 244 ± 23 mm (96 ± 3%), respectively. We did not differentiate between the superficial and deep heads of the muscle (Table 1 and Table 2).

The average origin of the radial artery was 32 ± 9 mm from the proximal border of the head of the radius (caput radii). All PQMs had at least one muscle branch of the radial artery, which was found, on average, at 190 ± 23 mm (83%) from the radial head. Among the PQMs, 85% (17 out of 20) had a second muscle branch, 20% (4 out of 20) had a third branch, and 10% (2 out of 20) had a fourth branch (Table 3, Figure 1, and Figure 2).

Furthermore, a correlation was observed between the length of the radius and the location of the first radial muscle branch, as indicated by the Pearson Correlation coefficient: the first muscle branch branched out from the radial artery with an increase in the length of the radius bone. However, no correlation was found between the weight or length of the PQM and the number of its muscle branches.

We confirm the innervation of the PQM by the anterior interosseous nerve (AIN). Measured from the radial head, the AIN originated between the first and second proximal quarter of the radius bone, with an average proximal measurement from the radial head at 52 ± 12 mm (23 ± 4%) and an ulnar measurement from the olecranon at 79 ± 17 mm (31 ± 5%) (Table 4).

DISCUSSION

The therapy goal of facial reanimation surgery is the reconstruction of static and emotional dynamic symmetry [13–16]. The diversity of facial reanimation procedures indicates the individualized treatment concepts that account for the specific patients' symptoms and deficits [17]. Iatrogenic causes are the most common etiologies of facial palsy [18]. Facial nerve injuries may manifest after the surgical removal of cerebellopontine tumors, acoustic neuromas, parotid masses, or the development of tumors along the path of the facial nerve [18]. In certain instances, iatrogenic facial palsy arises from deliberate R0 tumor resections, characterized by the achievement of clear margins at both macroscopic and microscopic levels. Conversely, there are situations where postoperative facial nerve deficits occur unexpectedly [18]. In oncological cases, postoperative facial palsy needs to be differentiated from preexisting facial weakness caused by the tumor. Neoplastic causes account for around 5% of facial palsy cases and are usually characterized by gradual onset of facial weakness [19,20]. In cases of oncological facial nerve resection, the timing of facial nerve repair and facial reanimation are crucial, as denervated facial muscles undergo atrophic changes which limit their potential for reinnervation [21,22]. Direct nerve repair, early interposition nerve grafting [23], even in proximal injuries close to the brainstem during cerebellopontine tumor surgery [21,24,25] and other facial reanimation procedures provide the optimal basis to regain facial nerve function. Additionally static procedures are recommended to be used in combination with dynamic facial reanimation to improve facial function in patients with significant comorbidities and limited life expectancy who are not suitable for complex multi-stage reconstructions [26]. Even in cases with planned postoperative radiation, complication rates following static procedures are low [27]. Moreover, in oncological resections, treatment planning not only has to address reinnervation and the restoration of missing mimetic muscles, but also consider soft tissue reconstruction for possible radiation therapy [16,28].

Reports of immediate facial reanimation techniques that combine

Table 2. Distal Borders of the PQM in Correlation With the Lengths of the Radial and Ulnar Bones[1]

Distal borders of PQM	n	Mean (SD), mm	Percentage of the total length of both bones (SD), %	Minimum, %[2]	Maximum, %[3]
From the radial head	20	218 (23.4)	95 (4)	88	100
From the olecranon	20	244 (22.6)	96 (3)	91	100

[1]The distal borders of the pronator quadratus muscle show a correlation with the lengths of the radial and ulnar bones. Notably, there exists a greater discrepancy between these borders on each side. On the radial side, the distal border is situated between 88% and 100% of the radial bone length, whereas on the ulnar side, it is positioned within the range of 91% to 100% of the ulnar bone length.
[2]The minimum length of the distal PQM borders in correlation with the lengths of the radial and ulnar bones is expressed as a percentage.
[3]The maximum length of the distal PQM borders in correlation with the lengths of the radial and ulnar bones is expressed as a percentage.
Abbreviations: PQM, pronator quadratus muscle; SD, standard deviation.

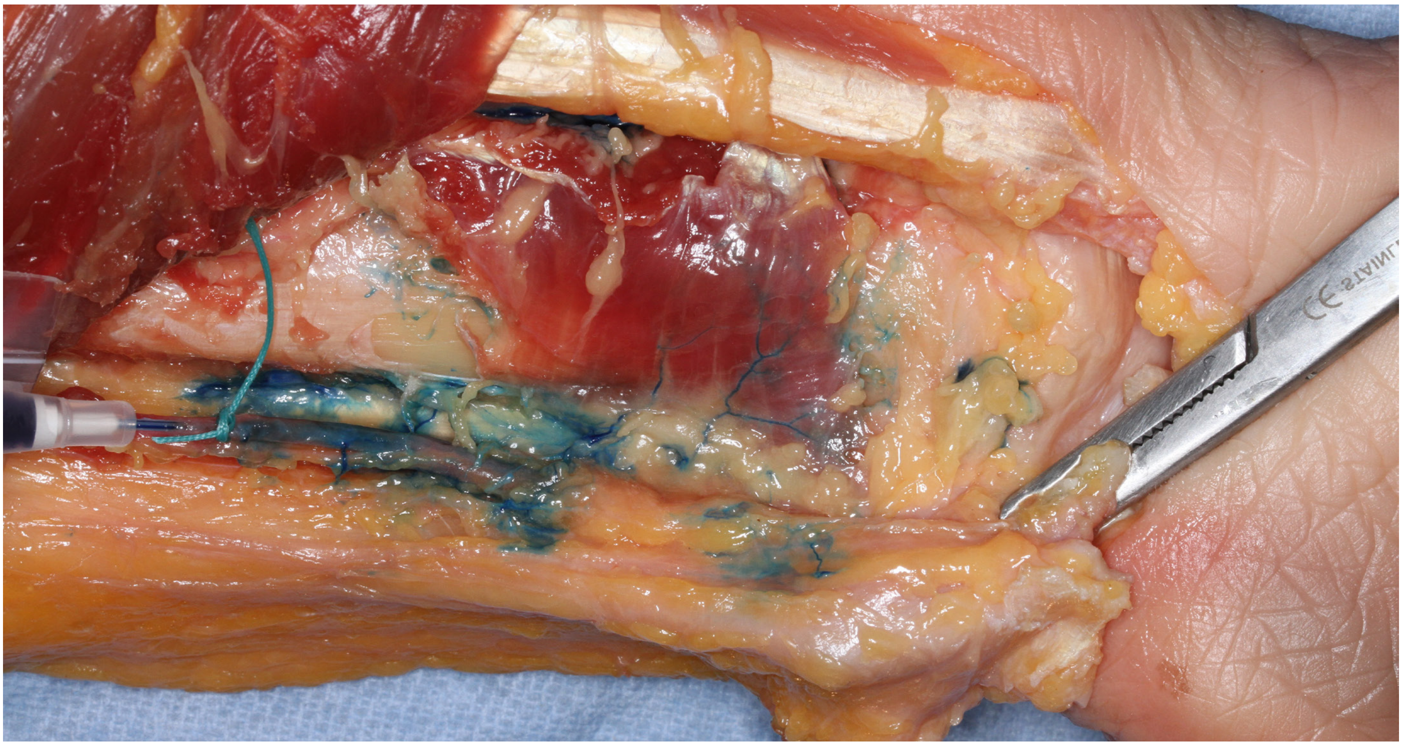

Figure 1. The pronator quadratus muscle perforators of the radial artery in the right forearm are stained with methylene blue.

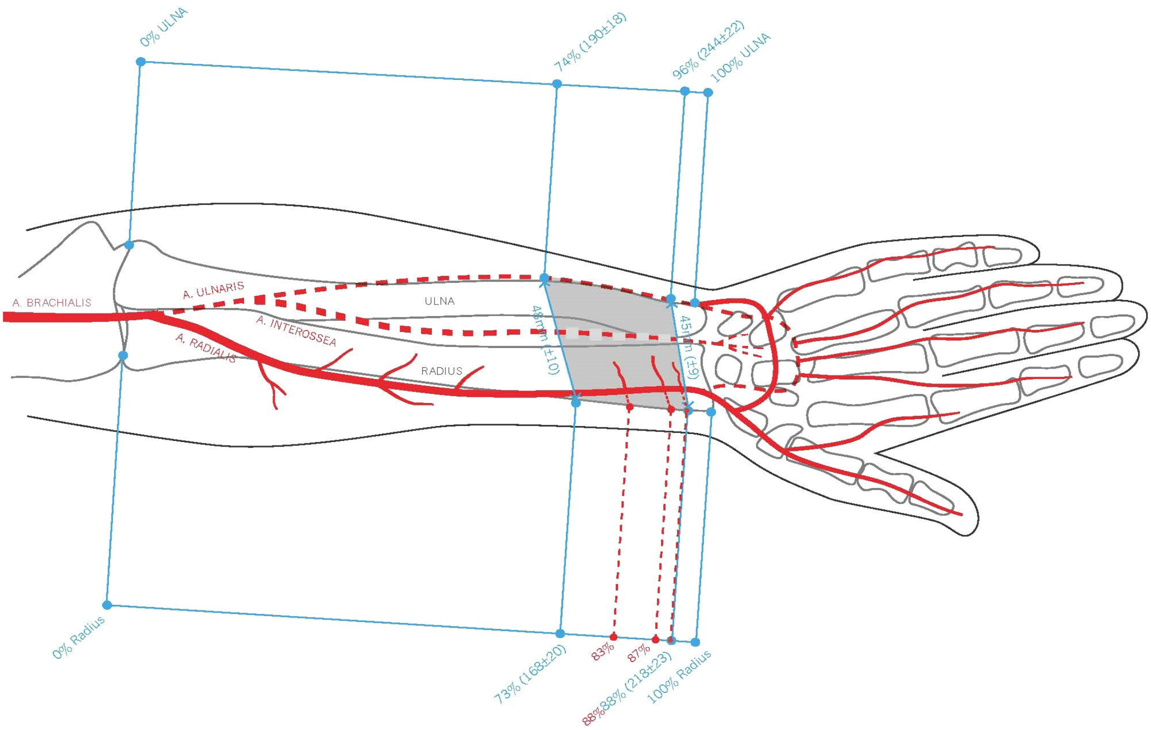

Figure 2. This comprehensive illustration provides a detailed view of the pronator quadratus muscle (PQM), its blood supply, and the relative positions of the radius and ulna within the right forearm. The PQM is highlighted, with the entire lengths of the forearm bones (radius and ulna) marked in grey and outlined in blue. The proximal border of the PQM on the radius is marked at 73%, while the distal border is marked at 88%. Similarly, on the ulna, the proximal border of the PQM is marked at 74%, and the distal border at 90%. Additionally, the origins of the perforators from the radial artery are indicated in red at 83%, 87%, and 88%.

Table 3. Origin of the Radial Artery Perforators in Correlation With the Length of the Radius[1]

Radial artery perforators	n	Mean (SD), mm	Percentage of the total length of both bones (SD), %	Minimum, %[2]	Maximum, %[3]
Perforator 1	20	190 (23)	83 (5)	73	90
Perforator 2	17	199 (19.6)	87 (3)	83	93
Perforator 3	4	209 (17)	89 (3)	86	92
Perforator 4	2	230 (0)	88 (0)	86	86

[1]Every PQM has at least one perforator originating from the radial artery. Of these, 75% possess a second perforator, 20% have a third, and 10% even exhibit a fourth.
[2]The minimum length of the origin of the radial artery perforators in correlation with the length of the radius is expressed as a percentage.
[3]The maximum length of the origin of the radial artery perforators in correlation with the length of the radius is expressed as a percentage.
Abbreviations: PQM, pronator quadratus muscle; SD, standard deviation.

the reconstruction of soft-tissue skin defects with simultaneous functional neuromuscular reconstruction during oncological tumor resections are quite rare. The lateral circumflex femoral system has been utilized for repairing extensive defects in the head and neck regions, aiming to restore both facial aesthetics and dynamic function [29,30]. The surgical anatomy of the anterolateral thigh flap has been meticulously studied in the past [30–34]. Recent publications have described the innovative use of a chimeric approach, involving the transplantation of the PQM in combination with a radial forearm flap [12,35]. This technique has shown promising results for reanimating paralyzed faces without causing donor site morbidity.

Anatomic studies of the PQM showed a two-headed muscle. The superficial head of the muscle is more distal; it originates from the distal fourth of the ulna and inserts with its transverse fasciculi into the distal fourth of the anterior surface of the radius bone. The deep and more proximal head of the PQM has oblique fasciculi extending from the proximal ulnar origin to the distal radial insertion. The origins of both heads are slightly apart, approximately 2 mm apart [36]. The superficial head is the prime mover in forearm pronation, whereas the deep head functions as a dynamic stabilizer of the distal radioulnar joint [37].

The muscle is innervated by the AIN, which arises from the median nerve at the radiohumeral joint line. AIN runs on the anterior surface of the interosseous membrane of the forearm and passes posterior to PQM, dividing into three or four terminal branches [38]. The nerve is accompanied by the anterior interosseous artery, which is the supplying artery of the PQM.

Due to the inadequate description of anatomic landmarks for the PQM in the literature, this study was conducted to elucidate the anatomic features of PQM and its vascularization by the radial artery for clinical applications. The findings revealed that the average weight of PQM was 8 ± 3 g. This muscle, shaped like a trapezoid, had an average length of 50mm and a mean width of 45mm distally and 48mm proximally. On the radius, the proximal border of PQM averaged at 169 ± 21 mm from the radial head, which corresponds to 73 ± 3% of the radial bone length, and the distal border was at 218 ± 24 mm (95 ± 3%). On the ulnar aspect, the proximal and distal borders of PQM were 190 ± 18 mm (74 ± 4%) from the olecranon and 244 ± 23 mm (96 ± 3%), respectively (Table 1 and Table 2). In addition to the detailed measurements of the muscle's insertion and origin, as well as the origin of the anterior interosseous nerve, we established that PQM receives its blood supply from both the anterior interosseous artery and the radial artery. Up to four muscle branches originating from the radial artery supply PQM. There was no correlation found between the weight and size of PQM and the number of radial muscle branches. PQM is innervated by the AIN and can be harvested at length for nerve reconstruction. The origin of this nerve can be located between the first and second proximal quarters of the radial or ulnar bone.

Although a former study revealed differences between male and female specimens in connection with significantly greater radial-ulnar width ($p = 0.005$), area (length times width; $p = 0.006$), and volume ($p = 0.033$) of the PQM in male specimens, as well as a greater distance from the radial styloid to the distal arborization of the AIN ($p = 0.005$) compared with female specimens [39], we could not find any significant distinction in correlation to weight ($p = 0.46$) or length ($p = 0.2$) of male and female muscles.

The PQM is known to be active during grip strength. The superficial head of PQM contracts more actively when the forearm is in pronation, whereas the deep head constantly contracts in all positions. Both heads play a role in grip strength, with the superficial head contributing to pronation strength [40]. The attachment of PQM to the base of the ulnar styloid process is considered an important structure that prevents the head of the ulna from impacting against the carpal bones [38]. Despite these crucial anatomic functions of PQM, there have been no reports of donor site morbidity after harvesting PQM in the past [12,35,41].

One of the limitations of our study is the restricted number of specimens, which prevented us from correlating sex and laterality (dominant right or left hand) with the size/weight of PQM. A general limitation of anatomical studies is the inability to assess muscle function.

In this study, our aim was to analyze clinically relevant anatomical landmarks of the PQM and its blood supply. Our findings can provide surgeons with valuable information for specific planning and treatment, especially when utilizing PQM for reanimating a paralyzed face.

CONCLUSION

The combination of the pronator quadratus muscle with a radial forearm flap presents a safe and feasible alternative for facial reanimation, especially for reanimating a paralyzed face. There are up to four radial artery muscle perforators, each under 0.5 mm in diameter, that arise from the radial artery at the origin of the PQM. These perforators ensure a consistent blood supply to the PQM when elevated with a free radial forearm flap, forming a chimeric flap.

Table 4. Anterior Interosseus Nerve and Its Landmarks in Correlation With the Lengths of the Radial and Ulnar Bones

Anterior interosseus nerve	Mean (SD), mm	Percentage of the total length of both bones (SD), %
From the radial head	52 (12)	23 (4)
From the olecranon	79 (17)	31 (5)

Abbreviation: SD, standard deviation.

ARTICLE INFORMATION

***Correspondence:** Chieh-Han John Tzou, MD, PhD, Plastic and Reconstructive Surgery, Department of Surgery, Hospital of Divine Savior, Dornbacher Strasse 20-30, 1170 Vienna, Austria. Email: science@tzoumedical.com

Received: Jul. 17, 2023; **Accepted:** Sep. 25, 2023; **Published:** Nov. 23, 2023

DOI: 10.24983/scitemed.imj.2023.00176

Acknowledgements: We would like to express our gratitude to Maria Prieto Barea for creating the figure (https://www.mariaprietobarea.com). We have obtained the necessary permission for the use of the figure in this publication.

Disclosure: The manuscript has not been presented or discussed at any scientific meetings, conferences, or seminars related to the topic of the research.

Ethics Approval and Consent to Participate: The study adheres to the ethical principles outlined in the 1964 Helsinki Declaration and its subsequent revisions, or other equivalent ethical standards that may be applicable. These ethical standards govern the use of human subjects in research and ensure that the study is conducted in an ethical and responsible manner. The researchers have taken extensive care to ensure that the study complies with all ethical standards and guidelines to protect the well-being and privacy of the participants.

Funding: The author(s) of this research wish to declare that the study was conducted without the support of any specific grant from any funding agency in the public, commercial, or not-for-profit sectors. The author(s) conducted the study solely with their own resources, without any external financial assistance. The lack of financial support from external sources does not in any way impact the integrity or quality of the research presented in this article. The author(s) have ensured that the study was conducted according to the highest ethical and scientific standards.

Conflict of Interest: In accordance with the ethical standards set forth by the SciTeMed publishing group for the publication of high-quality scientific research, the author(s) of this article declare that there are no financial or other conflicts of interest that could potentially impact the integrity of the research presented. Additionally, the author(s) affirm that this work is solely the intellectual property of the author(s), and no other individuals or entities have substantially contributed to its content or findings.

Publisher Disclaimer: It is imperative to acknowledge that the opinions and statements articulated in this article are the exclusive responsibility of the author(s), and do not necessarily reflect the views or opinions of their affiliated institutions, the publishing house, editors, or other reviewers. Furthermore, the publisher does not endorse or guarantee the accuracy of any statements made by the manufacturer(s) or author(s). These disclaimers emphasize the importance of respecting the author(s)' autonomy and the ability to express their own opinions regarding the subject matter, as well as those readers should exercise their own discretion in understanding the information provided. The position of the author(s) as well as their level of expertise in the subject area must be discerned, while also exercising critical thinking skills to arrive at an independent conclusion. As such, it is essential to approach the information in this article with an open mind and a discerning outlook.

REFERENCES

1. Bruins TE, van Veen MM, Mooibroek-Leeuwerke T, Werker PMN, Broekstra DC, Dijkstra PU. Association of socioeconomic, personality, and mental health factors with health-related quality of life in patients with facial palsy. *JAMA Otolaryngol Head Neck Surg* 2020;146(4):331–337.
2. Frey M. Smile reconstruction using the gracilis muscle. *Operative Techniques in Plastic and Reconstructive Surgery* 1999;6(3):180–189.
3. Terzis JK, Manktelow RT. Pectoralis minor: A new concept in facial reanimation. *Plast Surg Forum* 1982;5:106–110.
4. Manktelow RT, Zuker RM. Muscle transplantation by fascicular territory. *Plast Reconstr Surg* 1984;73(5):751–757.
5. Hohman MH, Hadlock TA. Etiology, diagnosis, and management of facial palsy: 2000 patients at a facial nerve center. *Laryngoscope* 2014;124(7):E283–293.
6. Zabojova J, Thrikutam N, Tolley P, Perez J, Rozen SM, Rodriguez-Lorenzo A. Relational anatomy of the mimetic muscles and its implications on free functional muscle inset in facial reanimation. *Ann Plast Surg* 2018;81(2):203–207.
7. Weiss JBW, Spuerck F, Kollar B, Eisenhardt SU. Age-related outcome of facial reanimation surgery using cross face nerve graft and gracilis free functional muscle transfer-A retrospective cohort study. *Microsurgery* 2022;42(6):557–567.
8. Tzou CHJ, Rodríguez-Lorenzo A. *Facial Palsy: Techniques for Reanimation of the Paralyzed Face*. Cham Switzerland: Springer Nature;2021.
9. Harii K, Asato H, Yoshimura K, Sugawara Y, Nakatsuka T, Ueda K. One-stage transfer of the latissimus dorsi muscle for reanimation of a paralyzed face: A new alternative. *Plast Reconstr Surg* 1998;102(4):941–951.
10. Oh TS, Kim HB, Choi JW, Jeong WS. Facial reanimation with masseter nerve-innervated free gracilis muscle transfer in established facial palsy patients. *Arch Plast Surg* 2019;46(2):122–128.
11. Klebuc MJA. Facial reanimation using the masseter-to-facial nerve transfer. *Plast Reconstr Surg* 2011;127(5):1909–1915.
12. Tzou CH, Aszmann OC. Reanimation of the paralyzed face: Radial forearm-pronator quadratus muscle flap. *JAMA Facial Plast Surg* 2013;15(5):388–390.
13. Terzis JK, Konofaos P. Experience with 60 adult patients with facial paralysis secondary to tumor extirpation. *Plast Reconstr Surg* 2012;130(1):51e–66e.
14. Placheta E, Tzou CJ, Hold A, Pona I, Frey M. Facial synkinesia before and after surgical reanimation of the paralyzed face. *Plast Reconstr Surg* 2014;133(6):842e–851e.
15. Frey M, Michaelidou M, Tzou CH, Hold A, Pona I, Placheta E. [Proven and innovative operative techniques for reanimation of the paralyzed face]. *Handchir Mikrochir Plast Chir* 2010;42(2):81–89.
16. Sahovaler A, Yeh D, Yoo J. Primary facial reanimation in head and neck cancer. *Oral Oncol* 2017;74:171–180.
17. Gyori E, Mayrhofer M, Schwaiger BM, Pona I, Tzou CH. Functional results after facial reanimation in iatrogenic facial palsy. *Microsurgery* 2020;40(2):145–153.
18. Hohman MH, Bhama PK, Hadlock TA. Epidemiology of iatrogenic facial nerve injury: A decade of experience. *Laryngoscope* 2014;124(1):260–265.
19. Jackson CG, Glasscock ME, 3rd, Hughes G, Sismanis A. Facial paralysis of neoplastic origin: Diagnosis and management. *Laryngoscope* 1980;90(10 Pt 1):1581–1595.
20. Leonetti JP, Marzo SJ, Anderson DA, Sappington JM. Neoplastic causes of nonacute facial paralysis: A review of 221 cases. *Ear Nose Throat J* 2016;95(9):390–404.
21. Humphrey CD, Kriet JD. Nerve repair and cable grafting for facial paralysis. *Facial Plast Surg* 2008;24(2):170–176.
22. Bianchi B, Ferri A, Sesenna E. Facial reanimation after nerve sacrifice in the treatment of head and neck cancer. *Curr Opin Otolaryngol Head Neck Surg* 2012;20(2):114–119.
23. Schwaiger BM, Tinhofer I, Steinbacher J, Rath T, Meissl G, Tzou CHJ. Topographic facial nerve transplantation. *Int Microsurg J* 2021;5(1):1.
24. Albathi M, Oyer S, Ishii LE, Byrne P, Ishii M, Boahene KO. Early nerve grafting for facial paralysis after cerebellopontine angle tumor resection with preserved facial nerve continuity. *JAMA Facial Plast Surg* 2016;18(1):54–60.
25. Arriaga MA, Brackmann DE. Facial nerve repair techniques in cerebellopontine angle tumor surgery. *Am J Otol* 1992;13(4):356–359.
26. Michaelidou M, Tzou CJ, Gerber H, Stussi E, Mittlbock M, Frey M. The combination of muscle transpositions and static procedures for reconstruction in the paralyzed face of the patient with limited life expectancy or who is not a candidate for free muscle transfer. *Plast Reconstr Surg* 2009;123(1):121–129.
27. Kejner AE, Rosenthal EL. Lower facial reanimation techniques following cancer resection and free flap reconstruction. *Laryngoscope* 2016;126(9):1990–1994.
28. Fritz M, Rolfes BN. Management of facial paralysis due to extracranial tumors. *Facial Plast Surg* 2015;31(2):110–116.
29. Koshima I, Yamamoto H, Hosoda M, Moriguchi T, Orita Y, Nagayama H. Free combined composite flaps using the lateral circumflex femoral system for repair of massive defects of the head and neck regions: An introduction to the chimeric flap principle. *Plast Reconstr Surg* 1993;92(3):411–420.

30. Hasmat S, Low TH, Krishnan A, et al. Chimeric vastus lateralis and anterolateral thigh flap for restoring facial defects and dynamic function following radical parotidectomy. *Plast Reconstr Surg* 2019;144(5):853e–863e.
31. Rozen WM, Ashton MW, Pan WR, et al. Anatomical variations in the harvest of anterolateral thigh flap perforators: A cadaveric and clinical study. *Microsurgery* 2009;29(1):16–23.
32. Lakhiani C, Lee MR, Saint-Cyr M. Vascular anatomy of the anterolateral thigh flap: A systematic review. *Plast Reconstr Surg* 2012;130(6):1254–1268.
33. Wong CH, Wei FC. Anterolateral thigh flap. *Head Neck* 2010;32(4):529–540.
34. Yoshimatsu H, Steinbacher J, Meng S, et al. Superficial circumflex iliac artery perforator flap: An anatomical study of the correlation of the superficial and the deep branches of the artery and evaluation of perfusion from the deep branch to the sartorius muscle and the iliac bone. *Plast Reconstr Surg* 2019;143(2):589–602.
35. Grinsell D, Herle P. Composite pronator quadratus: Radial forearm free flap in functional lip reconstruction. *ANZ J Surg* 2019;89(7–8):940–944.
36. Johnson RK, Shrewsbury MM. The pronator quadratus in motions and in stabilization of the radius and ulna at the distal radioulnar joint. *J Hand Surg Am* 1976;1(3):205–209.
37. Stuart PR. Pronator quadratus revisited. *J Hand Surg Br* 1996;21(6):714–722.
38. Sakamoto K, Nasu H, Nimura A, Hamada J, Akita K. An anatomic study of the structure and innervation of the pronator quadratus muscle. *Anat Sci Int* 2015;90(2):82–88.
39. Hinds RM, Gottschalk MB, Capo JT. The pronator quadratus and distal anterior interosseous nerve: A cadaveric study. *J Wrist Surg* 2015;4(3):183–187.
40. Shin WJ, Kim JP, Kim JS, Park HJ. Sonographic quantification of pronator quadratus activity during gripping effort. *J Ultrasound Med* 2015;34(12):2269–2278.
41. Dellon AL, Mackinnon SE. The pronator quadratus muscle flap. *J Hand Surg Am* 1984;9(3):423–427.