OPEN

PRS GLOBAL OPEN

ORIGINAL ARTICLE

Reconstructive

Reexploring the Anatomy of the Distal Humerus for its Role in Providing Vascularized Bone

Logan W. Carr, MD
Sebastian M. Brooke, MD
T. Shane Johnson, MD
Brett F. Michelotti, MD

Background: The lateral arm flap is used for composite defects in need of vascularized soft tissue, skin, and bone. From its original description, the distal humeral metaphysis can be included with the flap, supplied by the periosteal extensions of the posterior branch of the radial collateral artery. We sought to reexplore the anatomy of the lateral arm to determine its utility as a donor site for vascularized bone.
Methods: Twelve fresh, silicone-injected cadaver dissections were performed. Arteriovenous anatomy, pedicle length and diameter, and anatomic variability as well as photo documentation was recorded.
Results: The distal extent of the deltoid, lateral intermuscular septum and lateral humeral epicondyle were identified before the dissection. A septocutaneous perforator was consistently located 10 cm proximal to the lateral humeral epicondyle, which could be used for a skin paddle to monitor. Harvest of a 1.5 cm × 2 cm corticocancellous bone graft was performed. Average pedicle length was 9.1 ± 1.1 cm, and average pedicle diameter was 1.74 ± 0.52 mm. The inferior lateral cutaneous nerve of the arm and the posterior cutaneous nerve of the forearm were consistently identified and preserved.
Conclusion: The predictable anatomy of the lateral distal humerus make it an ideal donor site for small segments of vascularized bone. *(Plast Reconstr Surg Glob Open 2018;6:e1636; doi: 10.1097/GOX.0000000000001636; Published online 12 January 2018.)*

INTRODUCTION

Fracture immobility with or without operative fixation is essential to promote bony union. Primary bone healing can occur with rigid fixation and direct apposition of bony edges. This leads to replacement of the bony matrix without the formation of callus. In secondary bone healing, the inflammatory cascade leads to the signaling of cells responsible for callus formation, deposition of woven bone, and finally reorganization of bone in the direction of the applied load. Micro-motion at the fracture site results in secondary bone healing. Nonunion can result, if there is excessive motion.

Vascularized bone grafts can be used to promote bony union when nonvacularized grafts have failed or for primary treatment of long-gap bony defects (greater than 6 cm).[1] By preserving donor osteocytes and osteoblasts, vascularized bone grafting leads to more reliable, accelerated healing, especially in traumatic or irradiated fields.[2] Pedicled, vascularized bone grafts can be used, but may be limited by pedicle length, torsion, or lack of locally available donor bone. Free vascularized bone grafts have been described as purely osseous grafts, such as the medial femoral condyle (MFC), or as part of composite flap.

The upper arm perforator anatomy was originally investigated by Cormack and Lamberty[3] in 1984, whereas Katsaros et al.[4] later described the clinical application of the lateral arm osteocutaneous flap. Seven years later, Katsaros et al.[4] published his experience with more than 150 lateral arm flaps where he included many modifications, demonstrating its versatility. His series included chimeric, vascularized tendon, neurosensory, fascia-fat, and osteocutaneous flaps.[4] Although it was a large series, only 11 osteocutaneous flaps were included, and no outcomes were reported.

The lateral arm flap was later used as an osteocutaneous, neurotized free flap for 3 traumatic thumb injuries.[5] All patients in this small series went on to union and achieved protective sensation with no flap losses. Haas et al.[6] also demonstrated the use of the free osteocutaneous lateral arm flap in distal tibia, head and neck, and in

From the Division of Plastic Surgery, Department of Surgery, Pennsylvania State University, College of Medicine, Hershey, Pa.

Received for publication September 14, 2017; accepted November 17, 2017.

Presented at the Annual meeting of the American Association for Hand Surgery, Nassau, Bahamas, January 2015.

Supported by DePuy-Synthes research grant.

DOI: 10.1097/GOX.0000000000001636

Disclosure: *The authors have no financial interest to declare in relation to the content of this article. The Article Processing Charge was paid for by the authors.*

thumb reconstruction. To our knowledge, there is a paucity of literature detailing the use of the lateral arm flap as a bone-only free flap.

We sought to reexplore the anatomy of the lateral arm flap, the radial collateral artery (RCA) and its blood supply to the lateral, distal humerus with the goal of defining the clinically relevant vascular anatomy of the region and better defining its role as a free, vascularized bone graft.

MATERIALS AND METHODS

Anatomical Basis

The RCA originates on the posterior aspect of the humerus from the profunda brachii artery. The radial nerve follows the profunda brachii artery in the spiral groove of the humerus and continues to course laterally with the RCA. Before meeting the lateral intermuscular septum (LIS), the RCA bifurcates into anterior and posterior branches. The anterior branch pierces the LIS and enters the flexor compartment of the arm accompanying the radial nerve. The posterior branch of the radial collateral artery (PBRCA) courses distally within the LIS. The brachioradialis and brachialis are located anterior to the LIS, and triceps brachii is found posteriorly.

As the PBRCA courses along the humerus distally, it provides multiple septocutaneous perforators. The first 3 perforators were previously described in cadaveric studies at an average distance of 10.7, 7.8, and 4.8 cm, respectively, measured proximally from the lateral epicondyle.[7] Multiple small nutrient branches have also been described. Distally, a dense anastomotic network branches from the PBRCA to supply the periosteum. This network provides arterial inflow to the lateral supracondylar ridge and lateral epicondyle.

The inferior lateral cutaneous nerve of the arm and the posterior cutaneous nerve of the forearm travel through this anatomic region. These aforementioned nerves consistently arise from the radial nerve and travel distally along the LIS. Their course then becomes more variable within the subcutaneous tissue near the second septocutaneous perforator at approximately 7 cm proximal to the lateral epicondyle.[7]

Cadaver Study

After approval from the Penn State Hershey Medical Center Department of Humanities, 12 fresh, complete upper extremities were dissected. All arms were prepared with red latex injection into the arterial system (Science Care, Phoenix, Ariz.). Demographic data were available for the specimens. Mean patient age was 72.6 years. Five right arms and 7 left arms were dissected. Ten cadaver arms were from male subjects and 2 were from female subjects. Careful examination of the arms revealed no obvious deformity. Review of the provided medical history revealed no prior trauma or surgery that may have distorted the anatomy.

The skin was marked from the deltoid tuberosity to the lateral epicondyle, which correlates with the underlying LIS and the path of the PBRCA. The expected location of the first and largest septocutaneous perforator was marked along this line, 10 cm proximal to the lateral epicondyle as previously described (Fig. 1).[7]

Upon incision along the LIS, the first septocutaneous perforator was easily identified and used as a landmark for dissection toward its bifurcation from the PBRCA. The LIS and PBRCA were identified between the brachialis and triceps brachii. The pedicle was dissected from proximal to distal, to the distal humeral metaphysis, where periosteal branching was identified (Fig. 2). After the distal extent of the lateral epicondyle was identified, the PBRCA was ligated before travelling posteriorly to anastomose with the recurrent interosseous artery.

Without violating the lateral collateral ligament or joint capsule, a 1.5×2 cm corticocancellous bone graft was harvested (Fig. 3) to include the periosteal branches and a small cuff of muscle (Fig. 4). This size was chosen as this vascularized bone graft is more likely to be used for smaller defects of the wrist and hand due to convenience of location. After the bone graft was harvested, the proximal PBRCA was ligated, just proximal to the bifurcation of the first septocutaneous perforator to complete the graft harvest. If necessary, more pedicle length can be obtained by dissecting the PBRCA more proximally.

The distance from the proximal-most aspect of the lateral epicondyle to the deltoid tuberosity was measured as well as the distance from the lateral epicondyle to the

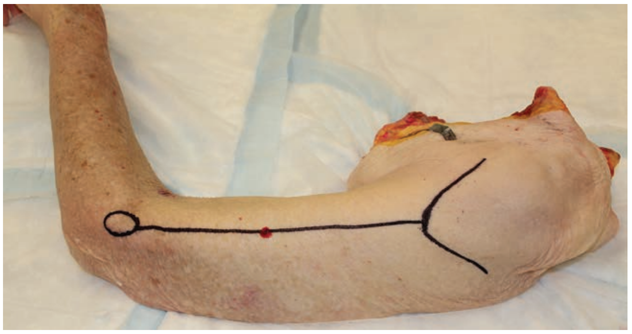

Fig. 1. Skin marking along a line extending between the deltoid tuberosity and lateral epicondyle, which indicates the location of the LIS and course of the PBRCA. The first septocutaneous perforator is located 10 cm proximal to the lateral epicondyle.

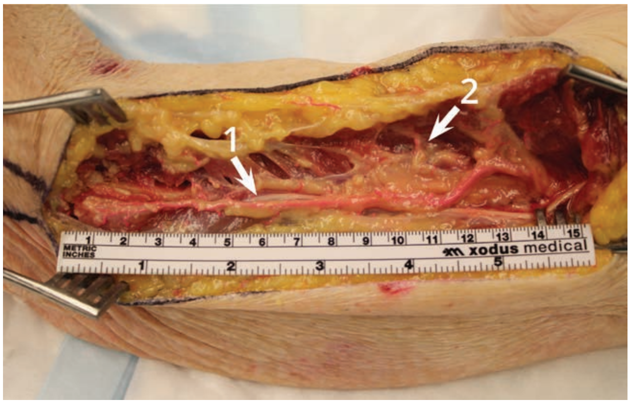

Fig. 2. PBRCA (1) with first septocutaneous perforators (2) and a rich periosteal vascular network.

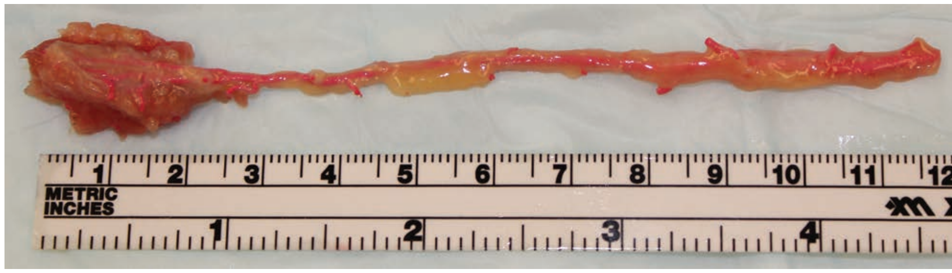

Fig. 3. Vascularized corticocancellous bone graft measuring 1.5 × 2.0 cm. A cuff of muscle was excised to protect the periosteal blood supply.

Fig. 4. Donor site following graft harvest. The dissection does not violate the elbow joint, and there is no disruption of the lateral collateral ligaments.

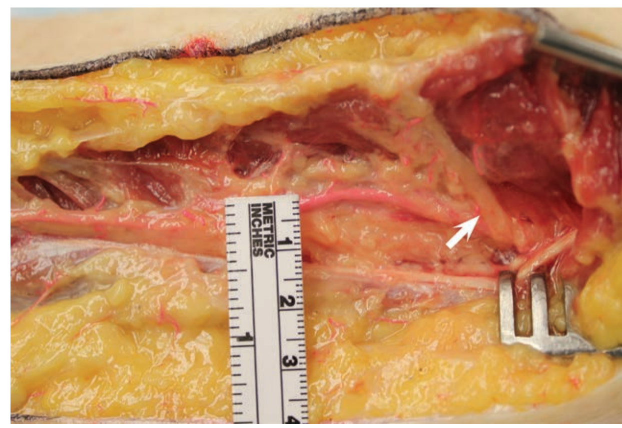

Fig. 5. Lateral cutaneous nerve of the arm (arrow) near the first septocutaneous perforator. Diameter of the PBRCA is also demonstrated.

first septocutanous perforator. The proximal caliber and length of the PBRCA pedicle was measured (Fig. 5). Any variation in anatomy was also noted.

RESULTS

The first septocutaneous perforator was present in 100% of the specimens. It was identified under the skin at an average of 10.0 cm from the proximal border of the lateral epicondyle at its intersection with the LIS. Mean pedicle length was 9.08 cm (range, 5–10.5 cm), and mean arterial diameter was 1.73 mm (range, 1.0–2.1 mm). Two associated venae comitantes were present with the PBRCA. Because they were not injected, their size could not be accurately quantified, but they were typically similar to the diameter of the artery or slightly larger.

There was no variability in the position of the PBRCA as it was present in all specimens and coursed along the postero-radial surface of the humerus. A dense periosteal blood supply was present in all specimens. This was observed distal to the bifurcation of the PBRCA with the anterior branch of the radial collateral artery. Care was taken to preserve the lateral cutaneous nerve of the arm and the posterior cutaneous nerve of the forearm as they were identified in all specimens branching from the radial nerve (Fig. 5).

DISCUSSION

Vascularized bone grafting can be used to bridge large bony gaps or to promote union in the setting of avascular necrosis. Scaphoid nonunion, Kienbock's disease, metacarpal, and metatarsal defects represent clinical scenarios in which small vascularized bone grafts may be of benefit.

Nonvascular or pedicled vascularized bone grafts are often utilized because of the close proximity to the affected area and lack of technical challenges associated with performing a microvascular anastomosis. First described in 1905, Huntington[8] repaired a large tibia defect with an ipsilateral, vascularized fibula. In scaphoid nonunion, the distal dorsal radius is the most commonly utilized donor site for pedicled vascularized bone grafts. Bone graft based on the 1,2 intercompartmental supraretinacular artery has provided union rates of up to 88%, though more recent data have shown union rates to be closer to 70%.[9,10]

Vascularized bone grafts preserve the osteocytes and osteoblasts of the donor tissue, leading to accelerated healing, especially in traumatic or irradiated fields with a tenuous blood supply.[2] However, local donor sites for pedicled vascularized bone grafts may not be available because of trauma and can be limited by pedicle length or torsion.

The lateral arm flap is a versatile flap for reconstructive surgeons.[11–13] Its use as an osteocutaneous composite flap has been reported in several series, though its use as a source of vascularized bone only, without soft tissue, has not been studied extensively.[3,4,14–17] A 1 × 1 × 10 cm bone graft can be harvested without compromising the structural integrity of the humerus.[4,7] The first septocutanous perforator can be a useful landmark during dissection, but more commonly it can be used to harvest a small skin paddle for clinical monitoring postoperatively.

We realize that pedicle length and diameter can vary based on the extent of proximal dissection. We chose to end our dissection and measure pedicle length at the bifurcation of the first septocutaneous perforator, which resulted in an average pedicle length of approximately 9 cm. This was an easy dissection and permitted enough pedicle length for the small bone flap, but avoided the morbidity of a more proximal dissection that could result in injury to brachial artery or profunda branch, radial nerve, or motor branch to the triceps.[18] Moffett et al.[18] also showed that the pedicle length could be doubled with an extended approach, but even then the diameter is variable and dissection tedious.

The MFC free vascularized bone graft has been used for repair of scaphoid nonunion in the setting of proximal pole avascular necrosis. Union rates approaching 100% have been reported in experienced hands.[19–24] The MFC flap has also been described for phalanx, metacarpal, forearm, humerus, and clavical nonunions with excellent union rates in all locations.[20]

Disadvantages of the MFC flap include potential donor-site morbidity, anatomic variability, and difficulty of graft harvest. Rare reports of insufficiency fractures after harvest have also been described.[20] The main pedicle of the flap, the descending genicular artery, has variable anatomy and is absent in 11% of patients.[25–27]

In our experience, there is variability in the pain that patients experience following the use of the MFC flap. Some patients report pain with ambulation for up to 3 months following the procedure. One potential advantage of the lateral arm osseous flap is that it is not harvested from a weight-bearing bone such as the femur perhaps limiting donor-site pain following the procedure. The arm as a donor site is also less prone to atherosclerotic disease and venous insufficiency relative to the lower extremity. Further study is needed to compare donor-site morbidity between the 2 flaps.

CONCLUSIONS

With this study, we have described the consistent anatomy of the PBRCA and have defined easily identifiable preoperative and intraoperative landmarks that make the distal humeral osseous free flap a predictable donor dissection. The lateral humeral metaphysis should be considered as a source of vascularized bone because of its consistent anatomy, ease of dissection, and its potential to generate less pain following harvest.

T. Shane Johnson, MD
Division of Plastic Surgery
Department of Surgery
The Pennsylvania State University
College of Medicine
H071
500 University Drive
Hershey, PA 17033
E-mail: tjohnson2@pennstatehealth.psu.edu

REFERENCES

1. Weiland AJ, Moore JR, Daniel RK, Vascularized bone autografts. Experience with 41 cases. *Clin Orthop Relat Res.* 1983;174:87–95.
2. Shaffer JW, Field GA, Goldberg VM, et al. Fate of vascularized and nonvascularized autografts. *Clin Orthop Relat Res.* 1985;197:32–43.
3. Cormack GC, Lamberty BG. Fasciocutaneous vessels in the upper arm: application to the design of new fasciocutaneous flaps. *Plast Reconstr Surg.* 1984;74:244–250.
4. Katsaros J, Tan E, Zoltie N, et al. Further experience with the lateral arm free flap. *Plast Reconstr Surg.* 1991;87:902–910.
5. Arnez ZM, Kersnic M, Smith RW, et al. Free lateral arm osteocutaneous neurosensory flap for thumb reconstruction. *J Hand Surg Br.* 1991;16:395–399.
6. Haas F, Rappl T, Koch H, et al. Free osteocutaneous lateral arm flap: anatomy and clinical applications. *Microsurgery.* 2003;23:87–95.
7. Hennerbichler A, Etzer C, Gruber S, et al. Lateral arm flap: analysis of its anatomy and modification using a vascularized fragment of the distal humerus. *Clin Anat.* 2003;16:204–214.
8. Huntington TW. The classic: case of bone transference. Use of a segment of fibula to supply a defect in the tibia. 1905. *Clin Orthop Relat Res.* 2012;470:2651–2653.
9. Chang MA, Bishop AT, Moran SL, et al. The outcomes and complications of 1,2-intercompartmental supraretinacular artery pedicled vascularized bone grafting of scaphoid nonunions. *J Hand Surg Am.* 2006;31:387–396.
10. Merrell GA, Wolfe SW, Slade JF 3rd. Treatment of scaphoid nonunions: quantitative meta-analysis of the literature. *J Hand Surg Am.* 2002;27:685–691.
11. Song R, Song Y, Yu Y, et al. The upper arm free flap. *Clin Plast Surg.* 1982;9:27–35.
12. Katsaros J, Schusterman M, Beppu M, et al. The lateral upper arm flap: anatomy and clinical applications. *Ann Plast Surg.* 1984;12:489–500.
13. Rivet D, Buffet M, Martin D, et al. The lateral arm flap: an anatomic study. *J Reconstr Microsurg.* 1987;3:121–132.
14. Katsaros J, Tan E, Zoltie N. The use of the lateral arm flap in upper limb surgery. *J Hand Surg Am.* 1991;16:598–604.
15. Waterhouse N, Healy C. The versatility of the lateral arm flap. *Br J Plast Surg.* 1990;43:398–402.
16. Gosain AK, Matloub HS, Yousif NJ, et al. The composite lateral arm free flap: vascular relationship to triceps tendon and muscle. *Ann Plast Surg.* 1992;29:496–507.
17. Harpf C, Papp C, Ninković M, et al. The lateral arm flap: review of 72 cases and technical refinements. *J Reconstr Microsurg.* 1998;14:39–48.
18. Moffett TR, Madison SA, Derr JW Jr, et al. An extended approach for the vascular pedicle of the lateral arm free flap. *Plast Reconstr Surg.* 1992;89:259–267.
19. Jones DB Jr, Moran SL, Bishop AT, et al. Free-vascularized medial femoral condyle bone transfer in the treatment of scaphoid nonunions. *Plast Reconstr Surg.* 2010;125:1176–1184.
20. Jones DB Jr, Rhee PC, Bishop AT, et al. Free vascularized medial femoral condyle autograft for challenging upper extremity nonunions. *Hand Clin.* 2012;28:493–501.
21. Jones DB Jr, Shin AY. Medial femoral condyle vascularized bone grafts for scaphoid nonunions. *Chir Main.* 2010;29:S93–103.
22. Mattiassich G, Marcovici LL, Dorninger L, et al. Reconstruction with vascularized medial femoral condyle flaps in hindfoot and ankle defects: a report of two cases. *Microsurgery.* 2014;34:576–581.
23. Sammer DM, Bishop AT, Shin AY. Vascularized medial femoral condyle graft for thumb metacarpal reconstruction: case report. *J Hand Surg Am.* 2009;34:715–718.
24. Larson AN, Bishop AT, Shin AY. Free medial femoral condyle bone grafting for scaphoid nonunions with humpback deformity

and proximal pole avascular necrosis. *Tech Hand Up Extrem Surg.* 2007;11:246–258.
25. García-Pumarino R, Franco JM. Anatomical variability of descending genicular artery. *Ann Plast Surg.* 2014;73:607–611.
26. Yamamoto H, Jones DB Jr, Moran SL, et al. The arterial anatomy of the medial femoral condyle and its clinical implications. *J Hand Surg Eur Vol.* 2010;35:569–574.
27. Rao SS, Sexton CC, Higgins JP. Medial femoral condyle flap donor-site morbidity: a radiographic assessment. *Plast Reconstr Surg.* 2013;131:357e–362e.
28. Chang EI, Ibrahim A, Papazian N, et al. Perforator mapping and optimizing design of the lateral arm flap: anatomy revisited and clinical experience. *Plast Reconstr Surg.* 2016;138: 300e–6e.