2510: Elbow vascularized composite allotransplantation - Surgical anatomy and technique

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Background
Elbow reconstruction with vascularized composite allotransplantation (VCA) may hold promise in treating end-stage arthritis, as no current treatment is both functional and durable. We describe the vascular and gross anatomy of the elbow in the context of VCA procurement, and propose a step-by-step surgical technique for elbow VCA.

Methods
Sixteen fresh adult cadaveric upper extremities underwent arterial tree latex injection. Arteries, nerves, and their branch points were identified and measured relative to the medial epicondyle. Based upon our determination of the dominant blood supply to elbow osseous and capsular structures, a cadaveric model of elbow VCA was derived by performing donor preparation on two fresh cadaveric upper extremities, with elevation of a lateral arm flap in conjunction with the vascularized elbow joint. Two size-matched specimens underwent recipient preparation, followed by transplantation. The surgical technique was refined with each successive transplant.

Results
The arterial supply to the elbow was comprised of consistent branches contributing to medial, lateral, and posterior arcades (Table 1). Preservation of the elbow arterial network requires sectioning of brachial, radial and ulnar arteries 12 cm proximal, 1 cm distal, and 6 cm distal to the ulnar artery take-off, respectively. Preservation of the supinator, anconeus, distal brachialis, proximal aspects of the flexor digitorum profundus, and flexor carpi ulnaris is required to protect osseous perforators. Nerves branches to the joint most commonly were derived from ulnar and median nerves (Table 1). Following two cadaveric elbow VCA procedures, our proposed surgical technique has been refined (Table 2).

Table 1.

| Blood Supply                        | Distance from Medial Epicondyle (cm) | Origin and Arcade Contribution | Structures Perfused |
|-------------------------------------|--------------------------------------|--------------------------------|---------------------|
|                                     | Average | Range  |                         |                     |
| Radial Collateral Artery (RCA)      | > 15*   | 18.0–23.0 | Profunda brachii - lateral | Lateral Trochlea, Capitellum, Capsulitis, Medial Olecranon |
|                                     | 19.9**  |         | Profunda brachii - lateral, posterior | Lateral Epicondyle, Capitellum, Medial Olecranon |
| Middle Collateral Artery (MCA)      | > 15*   | 18.0–23.0 | Medial Epicondyle, Medial Olecranon |
|                                     | 19.9**  |         | Medial Trochlea, Medial Olecranon |
| Superior Ulnar Collateral Artery (SUCA) | > 15*   | 13.5–23.0 | Brachial - medial | Olenar fossa, Medial Trochlea |
|                                     | 17.2**  |         | Medial Epicondyle, Medial Olecranon |
| Inferior Ulnar Collateral Artery (IUCA) | 5.6     | 5.0–6.0  | Brachial - medial, posterior | Medial Epicondyle, Coronoid Fossa, Medial Trochlea |
| Anterior Ulnar Recurrent Artery (AURA) | 5.2     | 4.2–6.0  | Ulnar - none | Mostly Muscular (Brachialis, Pronator Teres) |
| Posterior Ulnar Recurrent Artery (PURA) | 5.8     | 5.0–6.5  | Ulnar - medial | Medial Olecranon, Medial Trochlea |
| Recurrent Radial Artery (RRA)       | 4.1     | 3.3–5.5  | Radial - lateral | Radial Head/Neck, Capitellum |
| Recurrent Interosseous Artery (RIA) | 9.1     | 8.5–10.0 | Ulnar - posterior | Lateral Olecranon, Radial Neck, Capitellum |

(continued)
Table 1. (Continued)

| Nerve Supply                  | Branch Points Relative to Medial Epicondyle (cm) | Number of Branches |
|-------------------------------|--------------------------------------------------|--------------------|
|                               | Average | Range                      | Average | Range |
| Median                        | 2.7 distal | 4.5 proximal–5.0 distal | 2.1 | 0–5 |
| Ulnar                         | 0.5 proximal | 3.0 proximal–2.5 distal | 3.5 | 2–5 |
| Radial                        | 1.0 distal | 1.5 proximal–5.0 distal | 2.3 | 0–3 |
| Posterior interosseous (PIN)  | 8.1 distal | 6.5 distal–9.0 distal | 1.8 | 0–3 |
| Anterior interosseous (AIN)   | 7.6 distal | 6.0 distal–9.0 distal | 2.3 | 0–5 |

* Proximal to proximal extent of the cadaveric specimens.
** Based on past literature.

Table 2.

| Steps | Donor Preparation | Recipient Preparation | Transplantation |
|-------|-------------------|-----------------------|-----------------|
| 1     | Elevate a large lateral arm fasciocutaneous flap, and trace the pedicle back to the brachial artery. | Posterior approach: incise triceps fascia at midline, extend laterally about the olecranon tip, and continue distally along the ulna subcutaneous border. | Place the donor elbow into the recipient site. |
| 2     | Make an upper arm circumferential incision just distal to the axillary fold. | Identify and release the ulnar nerve (4.5 cm proximal to 9 cm distal from the medial epicondyle). | Perform osteosynthesis of the radius and ulna with lateral and posteromedial 3.5mm nonlocking plates, respectively. The recipient forearm and donor radius should be placed in full supination prior to plating. |
| 3     | Medial incision, elongate lateral incision proximally and distally after identification of the ulnar nerve. | Incise along the medial and lateral borders of the triceps tendon, and split it longitudinally along the midline. Sharply transect it at the olecranon insertoin to raise medial and lateral musculotendinous flaps to expose the posterior humerus. | Perform end-to-end microanastomosis of the donor and recipient radial, ulnar and median nerves proximally to the elbow joint. Anterioirly transpose the ulnar nerve in the subcutaneous tissue. |
| 4     | Elevation of anterior and posterior skin flaps to midforearm level, reflect both skin flaps distally. | Release the common flexor origin off of the medial epicondyle. | Suture the biceps tendon stump of the donor to the recipient tendon while preserving natural length of the musculotendinous unit. |
| 5     | Locate and expose the following structures just proximal to the elbow: Brachial artery and veins, median nerve, radial nerve. | Through the medial aspect of the posterior approach, locate and release the median nerve and brachial artery for a distance of 4.5 cm and 12 cm proximal to the medial epicondyle, respectively. Articular branches may be ligated. | Reduce the humerus diaphysis and provisionally fix with a heavy K-wire placed laterally. |
| 6     | Create proximally-based fasciotendinous flaps for the flexor and extensor origins with retained attachment to medial and lateral epicondyles, respectively. | Through the lateral aspect of the posterior approach, locate and release the radial nerve 4.5 cm proximal to the medial epicondyle. | Perform 90-90 plate osteosynthesis of the humerus (4.5mm posterior and 3.5mm lateral plates). |
| 7     | Circumferentially release nerves proximally, stopping 4.5 cm proximal to the medial epicondyle. Expose brachial artery to a point of 12 cm proximal to the arterial bifurcation. This will require excision of overlying flexor-pronator muscle. | Transversely section the humerus 9 cm proximal to the medial epicondyle with a reciprocating saw. | Through the medial aspect of the posterior incision, perform end-to-end microvascular anastomosis of the donor brachial artery and recipient brachial artery as proximally as possible. |
| 8     | Preserve fasciotendinous portions of the distal biceps and triceps. | Reflect the arm proximally through the osteotomized humerus to gain exposure to the anterior structures. | Suture the matching parts of the common flexor and extensor tendons while preserving natural length of the musculotendinous unit. |
| 9     | Expose the superficial surfaces of the arterial bifurcation, proximal 1 cm of the radial artery, and proximal 6 cm of the ulnar artery - do not dissect circumferentially to preserve the deep blood supply. | Isolate and release the distal part of ulnar, radial, and median nerves. Expose the posterior interosseous nerve, and release the radial tunnel to free it from the radius bone. | Suture the triceps tendon donor stump to the recipient triceps tendon, while preserving natural length of the musculotendinous unit. |
| 10    | Expose the superficial aspect of the median, ulnar and radial nerves for 9 cm proximal to the medial epicondyle (avoid circumferential dissection). | Isolate and release the proximal portion of radial and ulnar arteries, ligate branches to the elbow joint in the extension of 1 cm and 6 cm distally in respect to the arterial bifurcation respectively. | Ensure the pedicle is not twisted and kinked, then inset the lateral arm flap within the proximal part of the posterior incision. |
| 11    | To protect osseous perforators, preserve supinator, anconeus, proximal portion of FDP, FCU and distal aspect of brachialis muscle. Remove remaining superficial muscle. | Release the distal biceps insertion from the radial tuberosity. | Close the remaining wound. |
| 12    | Location of arterial sectioning relative to the ulnar artery take-off from the brachial artery: Brachial artery 12 cm proximally, radial artery 1 cm distally, ulnar artery 6 cm distally. | Osteotomize the radius 8 cm distal and ulna 10 cm distal to the medial epicondyle and remove the recipient elbow. | (continued) |
Conclusions

Elbow VCA may be technically feasible based upon its consistent vascular anatomy and our proposed surgical technique. Future studies evaluating elbow perfusion following cadaveric transplant would be revealing.