Vascular Perfusion of a Flexor Carpi Ulnaris Muscle Turnover Pedicle Flap for Posterior Elbow Soft Tissue Reconstruction: A Cadaveric Study

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Purpose The use of a pedicled flexor carpi ulnaris (FCU) muscle proximal turnover flap has been described previously for soft tissue reconstruction at the posterior elbow. Whereas consistent arterial supply to the FCU has been reported, the reliability of distal flap perfusion has not been confirmed. This study evaluated the vascular perfusion of an FCU turnover flap, based on the most proximal primary vascular pedicle that would permit a proximal turnover flap reconstruction to include the olecranon tip.

Methods In 12 fresh-frozen, proximal humeral human amputation specimens, the FCU flap was elevated from distal to proximal, preserving the most proximal primary vascular pedicle to the muscle belly that would permit flap coverage of the olecranon tip. The axillary artery was injected with India ink after ligation of radial and ulnar arteries at the wrist. After injection, each specimen was sectioned transversely at 0.5-cm increments to assess vascular perfusion of the muscle using loupe magnification.

Results The distance from the olecranon tip to the distal FCU muscle belly was 25.9 cm. The primary vascular pedicle that would facilitate creation of a proximal turnover flap was, on average, 5.9 cm distal to the olecranon tip. Perfusion of FCU muscle as measured distal to this primary pedicle was present in 50% to 100% of the muscle belly at an average of 8.9 cm beyond the pedicle. Perfusion of 25% to 50% of the FCU muscle belly was present at an average of 11.1 cm beyond the pedicle. Perfusion became less consistent (<25%) within the muscle belly at an average distance of 11.6 cm.

Conclusions Use of a proximally based, pedicled FCU muscle turnover flap provides a reliable option for soft tissue reconstruction at the posterior elbow. We observed consistent arterial perfusion of the muscle flap when preserving a proximal vascular pedicle 5.9 cm distal to the olecranon tip. *(J Hand Surg 2011;36A:246–251. Copyright © 2011 by the American Society for Surgery of the Hand. All rights reserved.)*

Key words Flexor carpi ulnaris, flap, soft tissue reconstruction, elbow, olecranon.

Successful treatment of soft tissue deficits at the elbow presents many challenges. Complex wounds, particularly those involving exposed bone, tendon, or hardware along the posterior aspect of the elbow, may require local or distant flap coverage. Traditional methods of posterior elbow soft tissue reconstruction involve the use of rotational flaps including the anconeus, brachioradialis, and extensor carpi radialis muscles[1–6]; fasciocutaneous flaps[7–11]; regional flaps such as a radial forearm flap, posterior interosse-

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ous artery flap,[5,7,9–13] or a latissimus dorsi flap[12,13]; and free tissue transfer such as a gracilis muscle flap.[5] These fascial or muscular flaps may be difficult to mobilize and may involve potential morbidity including partial or complete loss of the flap and inconsistent soft tissue coverage of the olecranon.[5]

Recently, the flexor carpi ulnaris (FCU) muscle was assessed in a cadaver model as a proximal turnover pedicle flap to provide soft tissue coverage of the posterior olecranon with consistent coverage of wounds observed 2 to 4 cm in width proximally at the olecranon tip.[14] The FCU is superficially located, which makes it easily accessible for flap harvest, with minimal donor morbidity.[15] The muscle belly lies within the ulnar arterial angiosome and is perfused by both the ulnar and posterior ulnar recurrent arteries. These vessels provide several vascular perforators to the muscle belly; however, the dominant arterial supply based on pedicle size comes from the ulnar artery.[16] The posterior ulnar recurrent artery consistently provides 2 to 3 pedicles to the muscle within the proximal third of the muscle, whereas the ulnar artery consistently provides 2 major pedicles, proximal and distal, to the muscle belly. The more proximal pedicle enters the muscle at the junction between the proximal and middle third of the muscle belly.[16] The distal pedicle consistently enters the muscle belly at the musculotendinous junction.[16] Despite these studies of vascular anatomy, however, we are unaware of previous studies that have evaluated the distal extent of arterial perfusion of the FCU muscle when used as a proximally based turnover flap for coverage of the posterior elbow, as described in the anatomical study by Wysocki et al.[14] Confirmation of the preservation of distal muscle perfusion after flap dissection and elevation is critical to validate its use in soft tissue reconstruction for defects over the olecranon, because this distal muscle is reflected proximally to cover the proximal portion of the soft tissue defect. Our purpose was to identify the primary pedicle as the most proximal arterial perforator within the proximal muscle belly that would perfuse the muscle sufficient to permit the muscle to be elevated from its insertion at the pisiform and turned over proximally to provide complete coverage of the olecranon.

MATERIALS AND METHODS

We obtained institutional review board approval for this study and used 12 fresh-frozen, transhumeral cadaveric amputation specimens. These specimens had no evidence of prior upper extremity trauma or surgical scars. The average age of the specimens was 68.3 years (range, 51–87 y) and specimens consisted of 7 right and 5 left extremities. Before use, the specimens were thawed to room temperature (21°C); all preinjection dissection and injection portions of the study were completed on the same day. We completed all dissections using 3.5× loupe magnification.

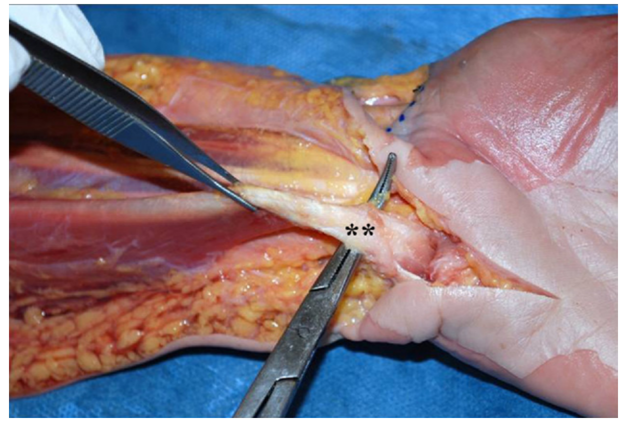

FIGURE 1: Dissection of the FCU tendon (asterisks) at its insertion. The distal extent of the FCU muscle belly may be appreciated here.

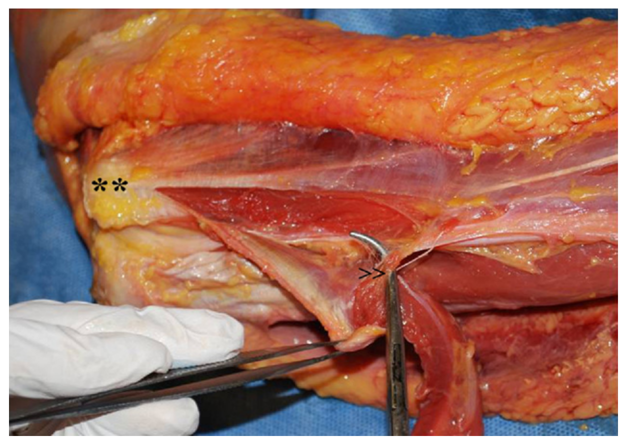

FIGURE 2: During distal to proximal elevation of the FCU, the most proximal primary pedicle to the FCU was identified (arrowheads), which permitted coverage of the posterior olecranon tip. The FCU origin is identified (asterisks).

In each specimen, we exposed the FCU at its insertion at the pisiform (Fig. 1) and elevated it from distal to proximal along the medial aspect of the forearm; we did not carry out flap elevation proximal to the identified primary vascular pedicle (Fig. 2). This primary pedicle was identified by elevating the muscle belly from ulnar to radial, exposing the vascular pedicles from the ulnar artery and the posterior recurrent ulnar artery to the FCU. We examined pedicles that perforated the FCU and identified the largest, most proximal pedicle that permitted the creation of a proximal turn-

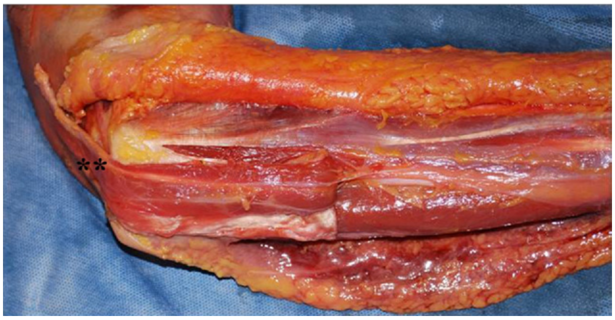

FIGURE 3: Cadaver dissection showing the position of the FCU turnover flap rotated on its primary pedicle, covering the proximal olecranon tip (asterisks).

over flap that provided complete muscular coverage of the olecranon tip as the primary pedicle for the purpose of this study (Fig. 3). Vascular pedicles that entered the muscle belly distal to this pedicle were ligated during flap elevation to isolate the FCU muscle belly from collateral flow that could occur distal to the primary pedicle.

We ligated the radial and ulnar arteries distally at the level of the wrist. At the level of the upper arm, we identified the axillary artery and cannulated it using a 14-gauge angiocatheter (Becton, Dickinson and Company, Franklin Lakes, NJ). We flushed the upper extremities with normal saline and observed saline extravasation from 1-cm incisions made in the digital pulps, confirming distal perfusion. After this saline flush, India ink (Dick Blick Art Materials, Tucker, GA) was injected into the axillary artery using a 14-gauge angiocatheter (Becton, Dickinson and Company). Extravasation of ink from the digital pulp incisions was confirmed. We cooled the specimens without refreezing for 24 hours before further evaluating the FCU muscle flap.

The following distances were measured using a millimeter ruler: (1) the proximal olecranon tip to the pisiform; (2) the pisiform to the distal-most aspect of the FCU muscle belly; (3) the pisiform to the primary vascular pedicle; and (4) the olecranon tip to the primary vascular pedicle.

After we obtained *in situ* measurements, we dissected the FCU muscle belly free from the specimen, preserving and marking anatomic landmarks (origin, insertion, and primary pedicle). Each specimen was sectioned transversely at 1-cm intervals distal to the primary vascular pedicle. Based on visual inspection using 3.5× loupe optical magnification, if the sectioned area was observed to have a relative decrease in the number of India ink-filled vessels, then the muscle sectioning was decreased to 0.5-cm increments. Each section was divided into 4 quadrants and examined under loupe magnification for presence or absence of India ink–filled vessels within each quadrant. If we were unable to identify ink-filled vessels in any quadrant, we categorized this as being less than 25% of the muscle belly. Perfusion distance was recorded as the distal extent of perfusion relative to the primary vascular pedicle.

RESULTS

The distance from the proximal pisiform to the tip of the olecranon ranged from 24.0 to 29.5 cm, with the average distance measuring 27.4 cm. The distance from the proximal pisiform to the most distal muscle fibers of the FCU ranged from 0.8 to 3.5 cm, with the average distance measuring 1.5 cm. Given the average values, the derived average muscle length from the olecranon tip to the most distal aspect of the FCU muscle was 25.9 cm. The average distance from the olecranon tip to the primary vascular pedicle was 5.9 cm, with a range of 5.2 to 6.8 cm.

Based on the primary pedicle, we observed the turnover FCU muscle flap to have vessel filling with India ink, interpreted as 50% to 100% vessel perfusion within all quadrants of the muscle at a distance of 8.9 cm (range, 6.4–10.4 cm) beyond the proximal pedicle and 14.8 cm (range, 12.3–16.3 cm) distal to the olecranon tip. The muscle was observed to have vessel filling within one quadrant, interpreted as 25% to 50% vessel perfusion, at a distance of 11.1 cm (range, 7.9–12.8 cm) distal to the primary pedicle and 17.0 cm (range, 13.8–19.3 cm) distal to the olecranon tip. It became difficult to visualize India ink filling of the vessels within the muscle quadrants, interpreted as less than 25% vessel perfusion, at a distance of 11.6 cm (range, 8.4–12.9 cm) distal to the primary pedicle and 17.5 cm (range, 14.3–19.8 cm) distal to the olecranon tip (Fig. 4).

DISCUSSION

Full-thickness wounds in the region of the posterior elbow present a challenge for treatment owing to the lack of underlying soft tissue coverage over the bony prominence of the olecranon. When soft tissue reconstruction is indicated, one should consider the character and location of the wound, the availability and feasibility of the donor flap, including the nature of donor site morbidity, and its capacity to allow early elbow motion. The size and complexity of the wound and the need to cover bone, hardware, tendon, or neurovascular structures, should be considered, also.

Several reconstructive options are available for restoring soft tissue coverage over the posterior surface of

FIGURE 4: Clinical case example of a patient with a draining sinus at the posterior elbow with underlying proximal ulna nonunion and chronic osteomyelitis. The area of poor soft tissue quality was excised at the time of surgery.

the olecranon,[5] ranging across the reconstructive ladder from local or regional flaps to free tissue transfer. Local or regional fasciocutaneous[5,7–13] or pedicled muscle flaps based on maintenance of dominant arterial perforating branches can provide coverage for defects about the posterior elbow.[5,12,15] Microsurgical free tissue transfer using various fasciocutaneous, myocutaneous, and muscle flaps, such as a free gracilis muscle or free anterolateral thigh flap transfer, may be considered.[5,12]

The radial forearm flap, a local fasciocutaneous flap based on the radial artery, can reach the posterior elbow, as a large flap (8 × 16 cm) with a large arc of rotation.[5,12] However, it is associated with potential morbidity including an unsightly donor site, potential loss of radial sensory nerve function, and sacrifice of the radial artery.[5,12]

A pedicled anconeus muscle flap is another source for coverage of periarticular elbow wounds, although the extent of coverage is limited by pedicle length.[1] It is useful for small posterior defects over the olecranon or the radiocapitellar joint, and its harvest results in a minimal loss of function related to terminal extension and supination of the forearm.[1,5] The arterial supply to the anconeus includes the recurrent posterior interosseus artery, the medial collateral artery, and a posterior branch of the radial collateral artery.[1,3] When harvested on the medial collateral artery that lies along the deep surface of the anconeus and anastomoses with the recurrent posterior interosseus artery, the muscle flap has been shown to reasonably cover up to 7.2 cm^2 over the posterior olecranon and 7.3 cm^2 over the radiocapitellar joint.[1] The recurrent posterior interosseus artery, which is the main arterial pedicle to the anconeus, is short (3.9 ± 0.3 cm) and can limit mobilization of an anconeus flap to cover the posterior elbow.[1] This artery can also inadvertently be injured with posterolateral elbow exposure.[1,5,16]

Because of its long pedicle, large size, and expendability, the latissimus muscle flap is a useful option for coverage of soft tissue defects. The latissimus is a large, broad muscle supplied by the thoracodorsal artery that can provide a large surface area for coverage of soft tissue defects.[17] The thoracodorsal artery most commonly branches from the subscapular artery or may branch from the axillary artery, and it averages 8.4 cm in length.[17] The entire muscle or the anterior portion of it, including a skin paddle, may be harvested up to the size of 12 × 35 cm, and can be tunneled into the arm from the axilla.[5] Because this flap has to be rotated along its pedicle and passed subcutaneously to reach the elbow, vascular compromise could result if the pedicle is twisted, stretched, or compressed.[17] This flap can have potential donor site morbidity, including distal flap loss, donor site seromas, and hematomas.[5,12]

A pedicled brachioradialis muscle flap has been described as an option for the reconstruction of posterolateral elbow wounds. The brachioradialis lies within the radial and brachial angiosomes and receives its blood supply from the radial recurrent artery, the radial artery, and the brachial artery.[15] The dominant artery supplying the brachioradialis muscle is variable; when using this muscle for posterior elbow coverage, both the radial recurrent artery and the radial arterial branches to the muscle need to be maintained to provide adequate perfusion to the flap.[2] Provided these pedicles are maintained, this flap can provide coverage to the region of the lateral epicondyle to the posterior olecranon, but it will not cover the region of the posteromedial elbow (medial epicondyle to medial olecranon).[2]

The FCU pedicle flap has been described as an option for soft tissue reconstruction of the posterior elbow.[14,18–21] A recent study by Wysocki et al.[14] quantified the potential utility of a proximal turnover pedicle flap for coverage of the posterior olecranon; however, the viability of the distal portion of the isolated muscle flap, based on arterial perfusion, was not determined in their cadaveric model. The FCU is a relatively superficial muscle along the posteromedial aspect of the forearm that does not require tedious dissection for flap harvest. Anatomical studies indicate that the FCU muscle belly is contained within the ulnar arterial angiosome and is supplied by both the ulnar artery proper and the posterior ulnar recurrent artery, with the ulnar artery providing the dominant blood supply in 86% of cases.[16] The ulnar artery provides 2 major perforating vessels,

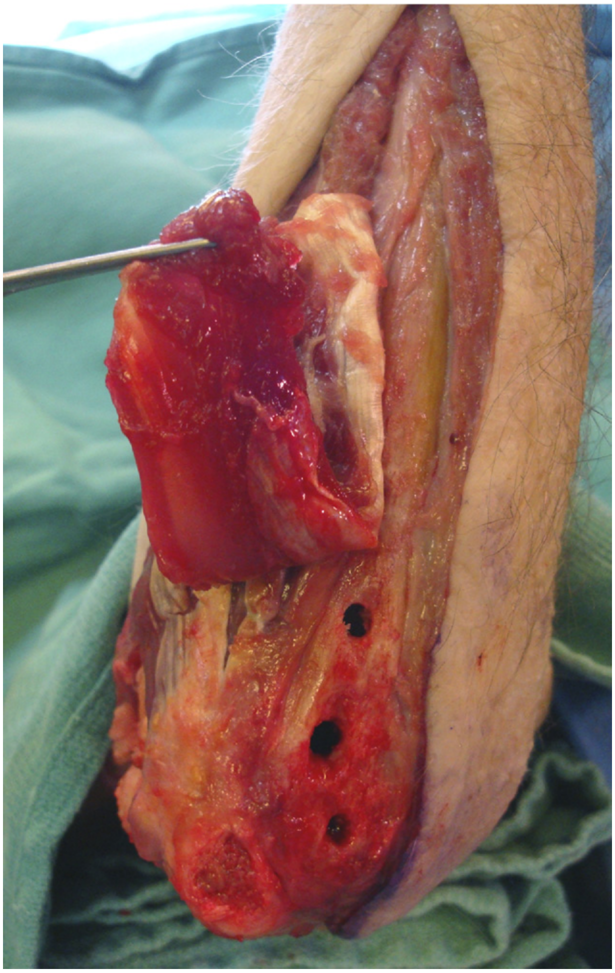

FIGURE 5: After debridement, a proximally based FCU muscle turnover flap was elevated for wound reconstruction.

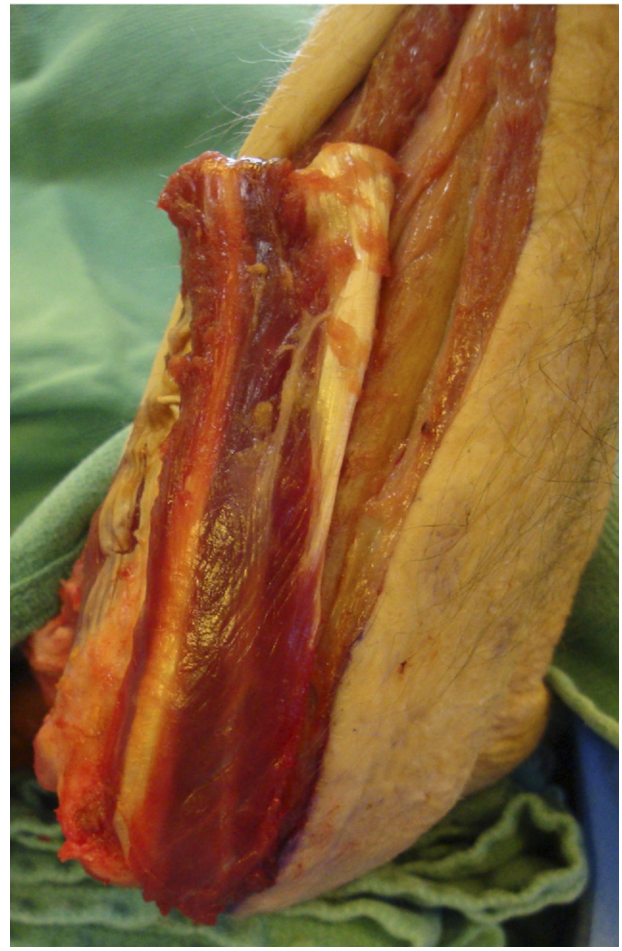

FIGURE 6: The FCU muscle flap permitted adequate coverage at the posterior elbow, including the olecranon tip. In this case example, primary wound closure was achieved without need for skin grafting or use of a myocutaneous flap.

with the most superior perforator entering between the proximal and middle thirds of the muscle; the interior perforator often enters at the musculocutaneous junction.[16]

The consistency of arterial supply to the FCU facilitates its use as a turnover flap for the posterior elbow; however, the reliability and extent of perfusion to the distal muscle after flap dissection have not been confirmed. In our study, we describe the vascular perfusion of the pedicled FCU turnover flap, based on the most proximal primary vascular pedicle that permitted creation of a turnover flap sufficient in length to reliably cover the olecranon tip. Our data indicate that the most proximal primary pedicle that would achieve this goal was, on average, 5.9 cm from the tip of the olecranon. The average distance from the olecranon tip to the distal tip of the FCU muscle belly was 25.9 cm, leaving approximately 19.8 cm of FCU muscle available to rotate over the olecranon. Based on the primary pedicle, the FCU muscle belly was perfused (interpreted as 50% to 100% vessel perfusion) within all quadrants of the muscular cross-sections at a distance of 8.9 cm distal to the primary pedicle, or 14.8 cm distal to the FCU origin/olecranon tip. The muscle was perfused in at least one quadrant, interpreted as 25% to 50% vessel perfusion, at a distance of 11.1 cm distal to the proximal pedicle, or 17 cm distal to the olecranon tip. Filling of the vessels within the muscle quadrants became inconsistent, interpreted as less than 25% vessel perfusion, at a distance of 11.6 cm distal to the primary pedicle, or 17.5 cm distal to the olecranon tip. When determining the distance of muscle belly available for coverage past the primary pedicle, our data indicate that approximately 11 cm of FCU muscle belly would be reliably perfused for use as a proximal turnover flap for reconstruction of the posterior olecranon (Figs. 4–6).

Limitations of our study include factors related to the use of cadaveric specimens for perfusion assessment, potential limitations of real or appreciated arterial perfusion with the India ink solution, and the limited number of specimens assessed in this anatomical study. Unappreciated arterial thrombosis or tissue injury may be difficult to recognize in a cadaveric model, limiting the interpretation of blood vessel filling. Despite the established use of India ink in previous studies to document musculotendinous arterial perfusion,[22–25] the use of loupe visualization or the limitations of India ink to completely fill the capillaries within the muscle may limit the ability to accurately interpret muscular perfusion.[2] Our study had a limited number of specimens, which may not account for variations in vascular anatomy. We recognize that patients with certain medical comorbidities such as collagen vascular disease, an immune-compromised state, or previous local tissue trauma or palsy may not be good candidates for use of the FCU flap and that treatment should be individualized. For flap coverage extending proximal to the olecranon tip, one must consider the position of the elbow during flap placement because changes in relative flap length may be influenced by elbow flexion-extension. A statistical analysis of our results, uncommon for anatomical studies, was not performed.

Reliable donor sources for soft tissue reconstruction of the posterior elbow, to and including the olecranon tip, include free tissue flaps and local or regional pedicled muscle flaps such as the FCU. The FCU has a consistent blood supply from the ulnar artery and posterior recurrent ulnar artery, facilitating the formation of a viable proximal turnover muscle flap for coverage to the proximal olecranon. When this flap is based on a primary arterial pedicle approximately 5.9 cm distal to the tip of the olecranon, reliable perfusion is preserved on average 11 cm distal to the primary pedicle, or 17 cm distal to the olecranon tip, which facilitates coverage to the olecranon tip. However, our results suggest the need for caution with attempts at expanded use of the flap because there may be insufficient or inconsistent perfusion of the distal 8 to 10 cm of muscle for its reliable use in similar soft tissue reconstruction procedures. We are considering a study using fluorescein injection intraoperatively during flap elevation to assess clinically the distal extent of flap perfusion and to confirm the current study findings.

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