Functional anconeus free flap for thenar reconstruction: a cadaveric study

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Abstract

Background Restoration of thumb opposition when significant thenar soft tissue defects occur remains a considerable surgical challenge. While several clinical applications of the anconeus muscle have been developed, free functioning muscle transfer (FFMT) of the anconeus for thenar reconstruction has not been reported previously. This study therefore sought to describe anatomical features of the anconeus that would determine its suitability for use as a FFMT.

Methods The anconeus, its corresponding abductor pollicis brevis (APB), and the supplying neurovasculature in eight

white British cadaveric upper extremities were identified and dissected. Measurements were performed using standard calipers and ImageJ 1.45d for a quantitative description of muscle architecture and the neurovasculature involved in the operative planning of the anconeus FFMT.

Results The mean measures of the anconeus were larger than those of the APB (anconeus/APB fiber length = $88.0 \pm 9.9/57.7 \pm 9.0$ mm, area = $1,341.9 \pm 230.4/987.7 \pm 251.2$ mm²). There was no significant difference between mean fiber angles (anconeus/APB = $70.5 \pm 11.9^\circ/78.4 \pm 12.2^\circ$; $p > 0.05$) and neurovasculature (anconeus/APB: artery diameter = $1.9 \pm 0.2/2.0 \pm 0.5$ mm, nerve diameter = $1.7 \pm 0.3/2.1 \pm 0.4$ mm; $p > 0.05$). The length (31.3 ± 6.9 mm) and caliber (diameter = 1.9 ± 0.2 mm) of the vascular pedicle of the anconeus (recurrent posterior interosseous artery) and its venae comitans (diameter = 1.0 mm) are sufficient for microsurgical anastomosis.

Conclusions The anatomic rationale of the anconeus FFMT for thenar reconstruction is sound and, compared to other FFMTs, may provide several advantages: reliable and matching anatomy, minimal donor site morbidity, and the potential to restore a greater degree of opposition and thus function in a one-stage procedure.

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Introduction

A functioning hand is one that is capable of thumb opposition for the fingers to grip or grasp. This ability of the hand is also known as prehension and has been described previously by Tubiana as “a complex function of the hand that gives it mechanical precision combined with a standard sensory pattern” [13].

Prehension may be lost due to significant soft tissue defects arising from a myriad of injuries that include those with composite tissue loss such as mechanical, thermal, and electrical injuries or iatrogenic defects secondary to tumor excision. The hand with such composite tissue loss would require microsurgical reconstruction for the optimal restoration of both its form and function.

Increasing knowledge about the anatomy of the anconeus [10] and advances in surgical technique have led to the development of several clinical applications. This includes its increasing use as a local flap for elbow reconstruction [2, 7] as well as studies looking into its potential use as a free flap for the reconstruction of hand and forearm defects [3, 8]. The aim of this study is therefore to investigate the clinical and surgical anatomy involved in the operative planning of free functioning muscle transfer (FFMT) of the anconeus for thenar reconstruction.

Materials and Methods

Cadaveric Study

Eight white British cadaveric upper extremity specimens (mean age=74±9 years; $F=5$; $M=3$) were dissected using standard surgical instruments. By making incisions using the proximal third of the ulnar border and the most prominent points of the lateral epicondyle of the humerus and the olecranon as landmarks (Fig. 1), the integument was dissected down to the enveloping antebrachial fascia around the underlying muscles. After the fascia was removed, the anconeus was identified, separated from

the adjacent extensor carpi ulnaris muscle, and then reflected using a distal–proximal approach, starting from its distal attachment along the ulnar border, with careful preservation of the supplying vessels branching from the recurrent interosseous artery. The radial nerve branch to the anconeus was identified by meticulous dissection along an oblique plane between the lateral epicondyle and the olecranon which was parallel to the fibers of the anconeus (Fig. 2). Within each cadaveric specimen, the skin and fascia overlying the thenar eminence were removed to expose the underlying musculature while maintaining the integrity of the superficial palmar branch of the radial artery with its venae comitans, and the recurrent branch of the median nerve, as they penetrated the thenar bulk.

Computer Analysis

For the purpose of this study, the proposed anconeus FFMT primarily seeks to replace the function of the corresponding abductor pollicis brevis (APB). Using ImageJ 1.45d (Rasband, W.S., ImageJ, U.S. National Institutes of Health, Bethesda, MD, USA, <http://imagej.nih.gov/ij/>, 1997–2011), the following were measured from digital pictures of the specimens according to Fig. 3:

- Dimensions of the anconeus
- Area covered by the anconeus
- Angle of orientation of the muscle fibers of the anconeus at quarterly intervals along the long axis of the muscle

These measurements were repeated for the ipsilateral corresponding APB for all specimens.

Fig. 1 Right arm specimen demonstrating landmarks used in dissection study. *LECH* lateral epicondyle of the humerus; *OLE* olecranon; *AM* anconeus muscle

Fig. 2 Oblique plane of dissection revealing the radial nerve branch to the anconeus muscle (*white arrow*). *AM* anconeus muscle; *LECH* lateral epicondyle of humerus; *OLE* olecranon; *TB* triceps brachii muscle

The following measurements were also performed using standard calipers:

- Length and diameter of the vascular pedicle and venae comitans of the anconeus
- Diameter of the radial nerve branch to the anconeus
- Diameter of the recurrent branch of the median nerve at its insertion into the APB
- Diameter of the superficial palmar branch of the radial artery and venae comitans at its insertion into the APB

All measurements were done in triplicate to allow for the influence of intra-observer variation. Inter-observer variation was not tested at this stage. Measurements were

compared between the anconeus and the APB of the same cadaveric specimen.

Results

Topographical Anatomy

The anconeus was larger than its corresponding APB. Their mean dimensions were 92 mm (range, 84 to 106 mm) by 86 mm (range, 73 to 97 mm) by 86 mm (range, 69 to 101 mm) and 59 mm (range, 47 to 71 mm) by 55 mm (range, 44 to 69 mm) by 59 mm (range, 48 to 72 mm), respectively (Figs. 3 and 5). The long axis of both muscles

Fig. 3 Measurements of the anconeus muscle. Dimensions: *black 1, 2, and 3*—lengths; *white 4, 5, 6, and 7*—widths; *white arcs 9, 10, 11, and 12*—muscle fiber angles; area was designated 8 but not shown. *LECH* lateral epicondyle of the humerus; *OLE* olecranon

were then determined and divided into four even quarters. The perpendicular to the long axis along these quarterly intervals was measured to provide a quantified account of the width of the anconeus and APB. In general, this perpendicular distance (i.e., the width) decreased along the long axis in both the anconeus and APB (Figs. 3, 4, and 5). The mean area covered by the anconeus was 1,342 mm² (range, 1,024 to 1,674 mm²) and that by the APB in the same cadaveric specimen was 988 mm² (range, 731 to 1,338 mm²). It can also be seen that within the same specimen, the anconeus was always approximately the same size if not, larger, than the APB (Fig. 6).

Muscle Architecture

The angle of orientation of muscle fibers at quarterly intervals along the long axis of both the anconeus and its corresponding APB followed the same general course: they began with an acute angle that gradually petered out and approached ninety degrees along the long axis of the muscle (Figs. 3 and 7). This allowed for the quantitative description of a pinnate muscle fiber arrangement which indicates a predominant function of the anconeus in force production. The mean fiber angle of the anconeus ($71 \pm 12^\circ$) was also not statistically different from that of the corresponding APB ($78 \pm 12^\circ$, $p > 0.05$).

Neurovascular Anatomy

In all our specimens, the recurrent posterior interosseous artery and its venae comitans were consistently present and are considered to be the vascular pedicle of the anconeus.

Fig. 4 The anconeus transfer. **a** Volar view of the palm with the abductor pollicis brevis exposed, demonstrating the recurrent median nerve (white arrow) and the palmar branch of the radial artery (black arrow). **b** The same specimen with the functional anconeus free flap in position. The recurrent branch of the median nerve (white arrow) lies against the ulnar margin of the flap, whilst the anconeus neurovascular bundle (black arrow) is of sufficient length to be mobilized

Fig. 5 Comparison of the mean measurements of the anconeus muscle and the corresponding abductor pollicis brevis

The mean length of this vascular pedicle was 31 mm (range, 24 to 41 mm) with an average diameter of 1.9 mm (range, 1.5 to 2.0 mm). The mean diameters of the radial nerve branch to the anconeus and the recurrent branch of the median nerve were 1.7 mm (range, 1.5 to 2.0 mm) and 2.1 mm (range, 1.5 to 2.5 mm), respectively. The diameters of the accompanying venae comitantes of the recurrent posterior interosseous artery and the radial artery were all at least 1.0 mm.

Biomechanics

The force output (F) of a muscle is proportionate to its cross-sectional area (CSA):

$$F = \text{Total CSA} \times \text{specific tension of muscle}$$

Fig. 6 Comparison of the mean area of the anconeus muscle and the corresponding abductor pollicis brevis within the same cadaveric specimen. *R* right, *L* left; *number after the letter* (e.g., L1) refers to the specimen number

Qualitative visual assessment suggests that the cross-sectional area of the anconeus muscle is at least as large as, if not bigger, than the APB. Hence, for the purpose of this mathematical analysis, erring of the side of caution, we assume that the CSA of both the anconeus and APB muscles to be the same. Next, it is assumed that the same amount of tension is generated during opposition of the thumb regardless of it being executed by the anconeus FFMT or APB. With a pennate arrangement of muscle fibers, F would be multiplied by a factor of the cosine of the fiber angle:

$$\cos(\text{fiber angle of anconeus}) = F(\text{anconeus}) / \text{CSA}(\text{anconeus}) \quad (1)$$

$$\cos(\text{fiber angle of APB}) = F(\text{APB}) / \text{CSA}(\text{APB}) \quad (2)$$

Fig. 7 Mean angle of orientation of muscle fibers at quarterly intervals along the long axis of the anconeus muscle and its corresponding abductor pollicis brevis

Therefore, combining (1) and (2):

$$\begin{aligned} F(\text{anconeus}) / F(\text{APB}) &= \cos(\text{fiber angle of anconeus}) / \cos(\text{fiber angle of APB}) \\ &= \cos(71) / \cos(78) \\ &= 0.33 / 0.21 \\ &= 1.57 \end{aligned}$$

It can thus be seen that the anconeus FFMT will be able to provide a force of contraction that is approximately 1.6 times that of the APB due to the orientation of the fiber angles.

Discussion

Hand injuries resulting in a loss of opposition and thus prehensile function cause significant functional and potential psychological morbidity. Established techniques can reliably restore thumb opposition and circumduction for the majority of etiologies (e.g., failed reinnervation) but may not be applicable when composite tissue defects exist after trauma, burns, or tumor excision. In these cases, tendon transfers or even the Huber opponensplasty requires flap cover for optimal function and restoration of thenar eminence volume to improve cosmesis and may also be necessary for wound healing. The use of a functional flap that provides soft tissue reconstruction and opposition is therefore attractive for a limited group of patients, as has been argued before [1]. However, the nature of the thenar musculature makes optimal reconstruction difficult. Existing FFMTs do not match thenar muscle morphology well, necessitating extensive intra-flap dissection (as with gracilis) or have unacceptable donor morbidity (as with extensor digitorum brevis [6, 12, 16]). They may also be a poor match for thenar muscle force dynamics (as with serratus anterior [4]). The nature of the small group of wounds that could indicate FFMT over traditional forms of reconstruction (tendon transfer, etc.) is such that there will be a mixed pattern of thenar muscle loss. It is the APB which is most critical for function and so this study aimed to compare the morphology of the anconeus to that thenar muscle. As with tendon transfers, the specifics of the muscle inset could be altered to give subtly different actions (pure abduction or composite circumduction, etc.) as indicated.

To the best of our knowledge, the anconeus has not been described previously for use in FFMT reconstruction of thenar defects. While early anatomical studies were equivocal about the suitability of the anconeus as a free flap [3, 8], the current study corroborates the favorable findings of Hwang et al. [3]: the recurrent posterior interosseous artery that supplies anconeus was consistently found in all eight of our specimens and it

was of a sufficient length and caliber (Table 1) as a free flap pedicle. It would match the diameter of the superficial palmar branch of the radial artery although that is not reliably present [5, 9] and so its length and caliber would permit routine use of end-to-side anastomosis with the radial artery. Venous anastomosis would be possible to the venae comitans of either vessel. The radial nerve branch to the anconeus has a diameter that approximates that of the recurrent branch of the median nerve (Table 1) and would theoretically provide a readily working muscle unit without the need for further nerve grafts. In addition, the current study has shown that the anconeus provides an almost perfect match for replacing the APB in terms of muscle function, size, and bulk (Fig. 4).

Therefore, it is theorized that the anconeus FFMT may have several advantages. First, the anconeus provides an ample area (Fig. 6) to allow the reconstructive surgeon to shape it according to the thenar defect to be reconstructed. Second, the operative anatomy appears to be consistent and reliable for easy harvest with minimal donor site morbidity despite concerns about the contributions of the anconeus toward elbow stability [11]. Finally and perhaps most importantly, the similarity in the orientation of muscle fibers of the anconeus and the APB (Fig. 7) may render the former an optimal candidate for the dynamic restoration of a greater degree of opposition movement to enable prehensile function in a one-stage procedure. While this does not take into account any limitations on muscle

excursion and thus force output such as scar tissue formation that would invariably become present in the in vivo setting postoperatively, a force output ratio of 1.6 between the anconeus FFMT and APB that it aims to replace suggests that the former would be an adequate functional replacement for the latter.

A further clinical question relates to skin cover since this flap is proposed for composite defects of the thenar eminence with loss of glabrous skin. Hence, the reconstructive ideal would be to restore stable, sensate, and glabrous cover, which is not directly afforded by this flap. Hwang et al. have demonstrated the possibility for the anconeus free flap to be raised as a myocutaneous one with an average skin area of 25.65 cm² [3]. This was not investigated further in this study as the current cadaveric model was not suitable for such purposes. The skin overlying the anconeus includes some skin from the olecranon area that is not grossly similar to glabrous skin but is relatively hypermobile, which would detract from grip stability. The muscle flap could be readily skin grafted to give adherent skin cover. This was found effective after the use of gracilis as a FFMT [1] and, in burns surgery, to be adequate for the majority. If surface instability subsequently developed, then resurfacing with glabrous skin grafts could be undertaken [14]. Plantar skin graft is not recommended in the first instance since donor sites are limited and prone to disabling donor morbidity, safely contouring and inseting it is comparatively difficult onto a new free flap that requires monitoring and room for swelling, and the risk of graft loss (and/or flap loss) is felt to be increased.

Reinnervation would clearly be required for the flap to be functional. The diameters of the proposed donor and recipient nerves approximate each other well but further studies incorporating histological staining techniques to determine the number of axons present for successful neurotization would ultimately be necessary before confirming the anconeus as a suitable FFMT.

Reconstruction of the mutilated hand optimally includes sensory restitution for maximal function to be achieved. The current study was set out to investigate the restoration of motor function rather than sensation. However, muscle reinnervation would afford deep sensation and proprioception. Depending upon the nature of the defect and the skin cover incorporated with the reconstruction, it may be possible to direct the reliably present palmar cutaneous branch of the median nerve [15] or other sensory branch towards improved sensory reconstruction. In summary, the anconeus has promising morphological, vascular, and gross motor nerve characteristics that merit its consideration for use as a FFMT in reconstructing select defects of the thenar eminence for which standard reanimation techniques are not applicable.

Table 1 Summary of analysis of measurements performed on specimens

Measurements (Fig. 3)	Anconeus muscle Mean (SD)	Abductor pollicis brevis Mean (SD)
1/mm	92 (10)	59 (9)
2/mm	86 (10)	55 (9)
3/mm	86 (11)	59 (9)
4/mm	25 (4)	24 (3)
5/mm	24 (3)	27 (4)
6/mm	17 (2)	19 (4)
7/mm	10 (1)	11 (2)
8/mm ²	1,342 (230)	988 (251)
9/°	59 (14)	70 (10)
10/°	68 (9)	74 (9)
11/°	78 (5)	82 (10)
12/°	77 (9)	87 (14)
Vascular pedicle		
Length/mm	31 (7)	–
Diameter/mm	1.9 (0.2)	–
Nerve diameter	1.7 (0.3)	2.1 (0.4) ^a

^a Recurrent branch of the median nerve

Conflict of interest The authors declare that they have no conflict of interest.

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