Posterior Elbow Coverage Using Whole and Split Flexor Carpi Ulnaris Flaps: A Cadaveric Study

Robert W. Wysocki, MD, Robert L. Gray, MD, John J. Fernandez, MD, Mark S. Cohen, MD

Purpose The purpose of this study is to evaluate the coverage patterns of whole and split flexor carpi ulnaris (FCU) pedicle muscle flaps for posterior elbow soft-tissue defects.

Methods Seventeen fresh-frozen cadaveric upper extremities were used. The whole FCU was raised to the dominant vascular pedicle and transposed proximally over the olecranon. The widths of coverage at 2-cm distances about the posterior elbow were measured. Widths were also measured after making 3 longitudinal cuts in the fascia and after suturing the muscle to adjacent soft tissue under tension. The FCU was also split into its ulnar and humeral heads along the central tendon. The larger ulnar head was transposed and the widths again measured. Mid-forearm circumference, elbow circumference, and ulnar length were assessed for ability to predict flap width.

Results The whole muscle under no tension provided an average of 2.7 cm width coverage at the tip of the olecranon process. Cutting the fascia provided approximately 15% additional width and suturing the muscle to the surrounding soft tissue an additional 25%, to approximately 4 cm. The isolated FCU ulnar head provided approximately 75% of the width of the entire muscle. Mid-forearm circumference was the most predictive of flap width, and divisors were generated that improved the accuracy of predicting the width for outlier specimens. The dominant pedicle was a consistent distance relative to the end of the central tendon and the olecranon tip.

Conclusions The whole and split FCU pedicle flaps provide predictable coverage for 2- to 4-cm posterior elbow soft-tissue defects. For especially large and small arms, the divisors improve accuracy in predicting flap width. Consistent locations of the olecranon tip and the end of the central tendon in relation to the dominant pedicle make them useful surgical landmarks. *(J Hand Surg 2008;33A:1807–1812.*

Key words Elbow soft-tissue defects, flexor carpi ulnaris flap, split flexor carpi ulnaris.

Soft tissue loss around the elbow can be difficult to treat. The posterior aspect of the elbow is particularly prone to skin coverage problems due to the subcutaneous nature of the olecranon, the lack of muscle and adipose tissue in this region, and the tension placed on the skin during elbow flexion. Posterior surgical approaches and hardware placed along the posterior ulnar border can contribute to skin breakdown. When wound defects exist with exposed bone, tendon, or hardware, local or distant flap coverage may be necessary.

Various options for coverage of posterior elbow soft-tissue defects have been described. These include local fasciocutaneous flaps[1,2] and muscle pedicle flaps such as the anconeous,[3,4] brachioradialis,[5] extensor carpi radialis longus,[6] and the flexor carpi ulnaris (FCU).[7–9] We have found the FCU to be an attractive local pedicle given its ease of elevation and adequate surface area to cover small to moderate-sized defects. Donor morbidity

From the Department of Orthopaedic Surgery, Rush University Medical Center, Chicago, IL.

Received for publication May 29, 2008; accepted in revised form August 26, 2008.

This investigation was performed at the Department of Orthopaedic Surgery, Rush University Medical Center, Chicago, IL.

No benefits in any form have been received or will be received related directly or indirectly to the subject of this article.

Corresponding author: Robert W. Wysocki, MD, 1725 West Harrison, Suite 1042, Chicago, IL 60612; e-mail: robertwysocki@mac.com.

0363-5023/08/33A10-0019$34.00/0
doi:10.1016/j.jhsa.2008.08.019

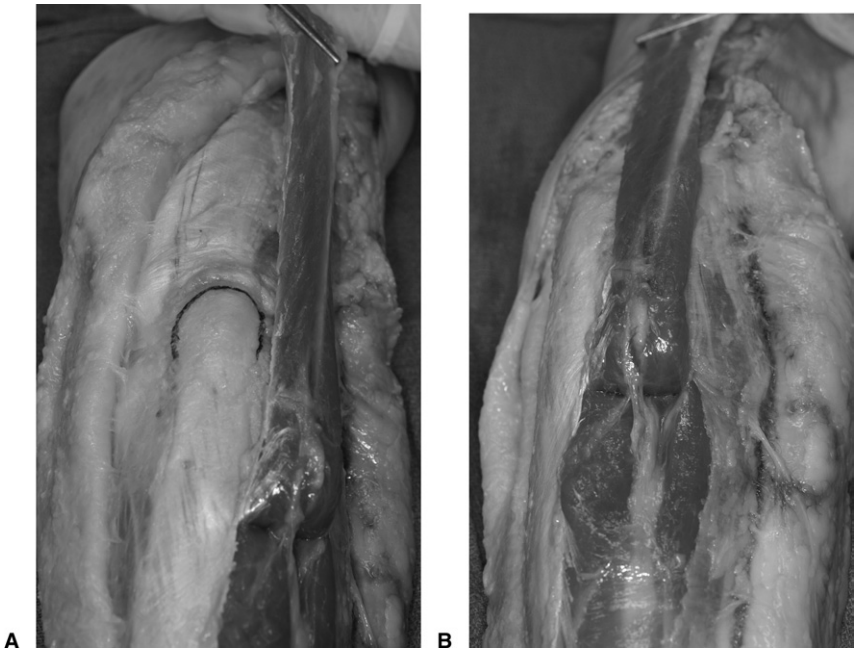

FIGURE 1: The whole FCU flap transposed proximally **A** adjacent to and **B** directly overlying the olecranon process.

using the FCU as a muscle flap has been shown to be minimal, and the vascular supply to the FCU has been well described, with the dominant pedicle being a branch of the posterior recurrent ulnar artery that enters the FCU in the proximal aspect of the muscle belly.[10] More recently, the unique bipennate nature of the FCU has been described, and use of the ulnar head of the split FCU transfer has been successfully applied to tendon transfers[11,12] and to local defect coverage.[13] This allows maintenance of some of the muscle's wrist flexion and ulnar deviation function by leaving the smaller humeral head of the muscle intact.

The goal of the current study was to describe the coverage patterns of both whole and split FCU local pedicle flaps for the posterior elbow. Attempts are made to predict muscle size and coverage based on measurements of extremity length and circumference.

MATERIALS AND METHODS

Institutional review board approval was obtained. Seventeen fresh-frozen cadaveric upper extremities amputated at the level of the mid-humerus were used. None of the specimens had a history of upper-extremity trauma or surgery. There were 8 male and nine female specimens, with an average age of 68 years (range, 56–77 years).

The first 12 specimens were used as follows. Prior to making an incision, the elbow circumference (C_e) was measured across both epicondyles with a standard tape measure. The ulnar length (L_u) from the tip of the olecranon to the tip of the ulnar styloid was measured. Lastly, the mid-forearm circumference (C_f) was measured. A longitudinal incision was made along the subcutaneous border of the forearm and arm. The skin and subcutaneous tissues were dissected back circumferentially, and the FCU was identified. The FCU tendon was sharply incised transversely, 2 cm from its insertion on the pisiform. The FCU muscle was elevated sharply from distal to proximal. Care was taken to identify the entry point of the dominant pedicle on the muscle's undersurface. The distance from the olecranon tip to the major pedicle was recorded. The distance from the proximal end of the central tendon to the dominant pedicle was recorded. The muscle was then folded upon itself and placed directly over the olecranon process without tension (Fig. 1). The width of the muscle flap was measured at the tip of the olecranon, as well as 2 cm distal and 2 cm, 4 cm, and 6 cm proximal to this point.

Next, longitudinal sectioning of the FCU fascia was performed. To standardize this, 3 longitudinal incisions were made in the fascia spaced equally apart over the length of the muscle being measured (Fig. 2). Width measurements at the same 4 locations were then recorded. The FCU was returned to its normal anatomic position, and the tendon was directly repaired end-to-end.

The FCU was then split into its humeral and ulnar heads. This was done in the fashion previously described by Lim et al.[11,14] The center of the tendon was

FIGURE 2: Standardized sectioning of the FCU fascia with 3 longitudinal cuts.

identified distally and sharply incised with a scalpel. This incision was then carried from distal to proximal the length of the central tendon into the proximal quarter of the muscle. This was done without cutting muscle fibers, but rather reflecting them off of the tendon proximally (Fig. 3). The larger ulnar half of the tendon distally was transected and rotated proximally over the olecranon (Fig. 4). The width of the muscle flap was measured at the olecranon tip, as well as 2 cm distal and 2 cm, 4 cm, and 6 cm proximal to this point.

In an effort to determine the effect of peripherally placed sutures on muscle coverage, 5 additional cadavers were dissected. The full FCU was elevated, the fascia longitudinally split, and the muscle was rotated to cover the olecranon as described above. Standardized measurements of width were made with the muscle under no tension at the olecranon tip as well as 2 cm proximal and distal to it. The muscle was then sutured to the adjacent soft tissue under light tension with interrupted sutures 1 cm apart on both sides of the muscle. Widths were then remeasured at the 3 locations above.

RESULTS

The mean mid-forearm circumference was 20.1 cm ± 3.0 (range, 15.3–24.0 cm). The mean elbow circumference at the level of the epicondyles was 25.1 cm ± 2.5 (range, 21.4–29.2 cm). The mean ulnar length was 26.6 cm ± 2.5 (range, 22.7–29.0 cm).

The widths of the whole FCU flap both before and after cutting of the fascia as well as the widths of the ulnar head of the FCU are shown in Table 1. These widths are listed in relation to the tip of the olecranon process. Creating 3 longitudinal splits in the fascia led to an overall mean increase in width of 15%, (range 11% to 16%) in all locations relative to the olecranon tip. With gentle manual traction of the flap edges, approximately 25% of additional flap width was achieved (range, 21% to 32%). The ulnar head of the FCU provided on average 73% of coverage when compared with the whole muscle width (range, 67% to 82%).

The mean distance from the olecranon tip to the major pedicle of the FCU was 5.0 cm ± 0.4 (range, 4.0–5.6 cm). The mean distance from the proximal extent of the central tendon to the major pedicle while performing the split was 2.4 cm ± 0.5 (range, 1.8–3.2 cm), with the pedicle always proximal to the end of the central tendon.

We attempted to use the mid-forearm circumference (C_f), elbow circumference (C_e), and ulnar length (L_u) to predict flap width. For the whole flap, we divided the 3 reference values for each specimen by the width of the whole flap at the olecranon tip after fascial splitting to create a predictive divisor. The mean divisor for C_f was 6.7 ± 1.0, for C_e was 8.5 ± 1.7, and for L_u was 9.1 ± 2.0. Thus, mid-forearm circumference (C_f) had the least variation and was the most predictive of the three. Each C_f for the 10 specimens was then divided by the divisor of 6.7 to yield a predicted width at the olecranon tip. Based on a mean width of 3.1 cm at the olecranon tip, the mean absolute difference between the predicted value and the actual value for the 4 specimens with a C_f greater than 1 standard deviation above or below the mean was 0.9 cm with a standard deviation of 0.3 cm. When using the widths predicted by the mid-forearm circumference divisor rather than simply the mean of 3.1 cm, the mean absolute difference between the predicted value and the actual value decreased to 0.4 cm with a standard deviation of 0.2 cm. This difference between the means was statistically significant ($p < .005$).

Using the same process to calculate divisors for the FCU ulnar head at the olecranon tip, the C_f was again most predictive with a divisor of 9.0 ± 0.9 compared with C_e (11.4 ± 1.5) and L_u (12.2 ± 2.1). Based on a mean width of 2.2 cm at the olecranon tip, the mean absolute difference between the predicted value and the actual value for the 4 specimens with a C_f more than 1

FIGURE 3: A The central tendon of the FCU with the muscle fibers reflected off, showing the well-defined proximal end of the tendon (arrow) within the muscle belly. **B** The FCU is split into its ulnar and humeral heads by dividing the muscle along the central tendon.

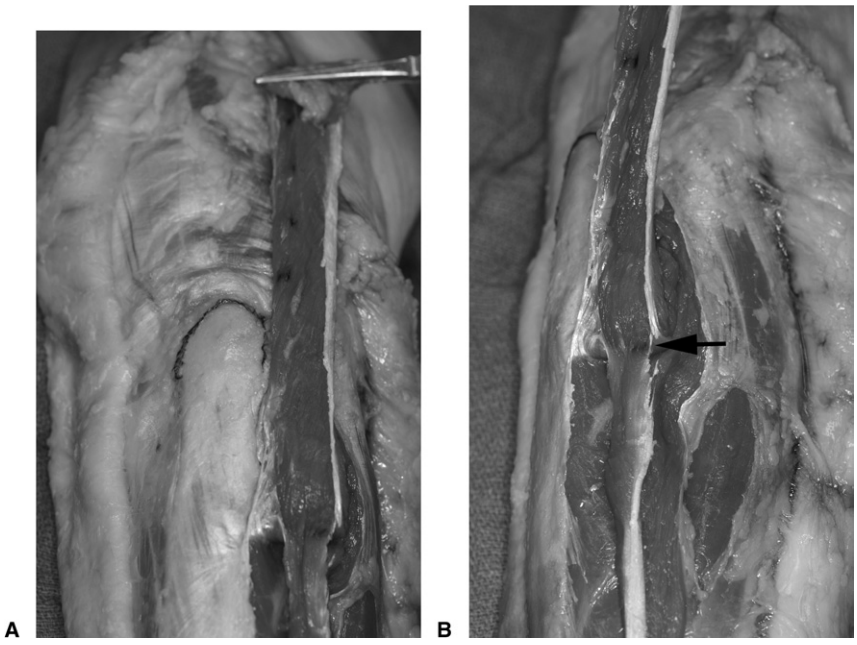

FIGURE 4: The ulnar head of the FCU transposed proximally **A** adjacent to and **B** directly overlying the olecranon process. The split extends up to the proximal end of the central tendon (arrow).

standard deviation above or below the mean was 0.6 cm with a standard deviation of 0.2 cm. When using the widths predicted by the mid-forearm circumference divisor, the mean absolute difference between the predicted value and the actual value decreased to 0.2 cm with a standard deviation of 0.1 cm. This difference between the means was statistically significant ($p < .005$).

TABLE 1. Width of FCU Flap Over Posterior Elbow

Location*	Whole Flap Width (cm)		Ulnar Head Width After† (cm)	Whole Flap With Traction After† (cm)
	Before†	After†		
−2 cm	2.7 ± 0.5	3.0 ± 0.6	2.2 ± 0.5	4 ± 0.7
OT	2.7 ± 0.6	3.1 ± 0.7	2.2 ± 0.5	4 ± 0.6
+2 cm	2.4 ± 0.6	2.7 ± 0.6	2.0 ± 0.5	3 ± 0.5
+4 cm	2.2 ± 0.5	2.6 ± 0.6	1.9 ± 0.5	Not measured
+6 cm	2.1 ± 0.5	2.4 ± 0.6	1.8 ± 0.5	Not measured

*Distance is in relation to olecranon tip (OT). Negative values are distal and positive values are proximal.
†Before versus after fascial cuts.

DISCUSSION

Soft tissue defects of the posterior elbow can occur secondary to trauma,[8,9] wound dehiscence after surgical procedures such as joint replacement,[15] burns,[16] radiation,[17] decubitus ulceration,[2] chronic inflammation, and bursitis.[18,19] The lack of muscle and subcutaneous tissue in this area and the tension applied to the skin during elbow flexion make this area prone to wound problems. Treatment of such soft tissue defects can be difficult, and, not uncommonly, local or distant flap coverage is required.

The radial forearm flap is probably the most popular of the fasciocutaneous flaps used in this area due to its large coverage area and arc of rotation.[20,21] However, it has been suggested that it may lack the degree of vascularity that a muscle flap would bring to the area.[22] There is also donor-site morbidity in the forearm with this transfer including cold intolerance, adhesion formation, poor healing over exposed tendons, and poor appearance.[23] The latissimus dorsi pedicle flap can be used for larger defects, especially posttraumatic, because it lies outside of the zone of injury.[23] However, this flap does carry a high complication rate including necrosis of the distal portion, making it difficult to use when defects extend well distal to the olecranon tip.[22] Finally, several local muscle pedicle flaps have been described to cover smaller defects of the posterior elbow. These include the anconeus,[3,4] brachioradialis,[5] and the extensor carpi radialis longus.[6] These muscles provide limited soft tissue coverage and can be technically difficult to raise.

The FCU muscle pedicle flap is a reliable tool to cover soft tissue defects of the posterior elbow.[7–9] The muscle is located directly along the posterior border of the forearm and is easily raised. We have used it at our institution to successfully cover posterior elbow defects secondary to trauma, wound dehiscence, and tumors. As the dominant flexor and ulnar deviator of the wrist,[24] there has been some concern over donor-site morbidity,[25,26] but the functional loss of strength in 1 study has not been shown to be clinically relevant.[27] More recently, it has been recognized that the FCU is a truly bipennate muscle with independent nerve and vascular supply.[14,28,29] The implication of these findings is that the FCU can be split into its larger ulnar and smaller humeral heads, both independently viable, with one being retained for wrist flexion and ulnar deviation strength and the other available for tendon transfer[11,12] or regional soft tissue coverage.[13] Pereira and co-workers in a primate study found that when independently stimulated, the ulnar and humeral heads generated greater collective force than did the muscle as a whole (92% and 82%, respectively, for each head).[29] This finding could be due to removal of the myotendinous connection between the 2 heads after splitting. Lingaraj et al. reported 2 cases of split FCU for regional soft tissue coverage. They found ulnar deviation strength remaining that was 80% to 100% of the unaffected side.[13]

We have defined the regional coverage patterns of the whole and split FCU flap for the posterior elbow. These pedicle flaps provide coverage of predictable width for the olecranon. On average, the whole muscle when rotated under no tension can cover defects of 2.7 cm in width at the olecranon tip. This can be expanded to 3.1 cm by longitudinally scoring the muscle fascia and up to approximately 4 cm with peripherally placed sutures. Although the amount of tension applied was somewhat subjective, it does suggest that additional flap width is possible with manually stretching the muscle from its contracted state to a width more closely approximating its resting tension. The position of the major pedicle is relatively consistent being located approximately 5.0 cm distal to the tip of the olecranon.

Using divisors based on mid-forearm circumference for the whole and split flaps can help more accurately predict

the width of the flap in patients with larger or smaller mid-forearm circumferences. For those outlier patients with a mid-forearm circumference greater than 23 cm or less than 17 cm, dividing the mid-forearm circumference in centimeters by the calculated divisors yields a projected flap width in centimeters at the olecranon tip that is more accurate than using the means alone for both the whole flap and the FCU ulnar head flap ($p < .005$).

There are several points to consider when applying this data clinically. In regard to the measurements under gentle traction, the specimens used in this study were from older individuals, and it is feasible that the more robust muscle belly of a young muscular patient may not stretch quite to the degree seen here. Despite this potential difference, the stretch we have encountered *in vivo* subjectively approximates our data.

Although we have not encountered tip necrosis clinically, we also caution against vigorous stretching at the tip of the flap due to the theoretical risk of necrosis. Fortunately, after transposing the FCU, the tip of the muscle usually rests well proximal to the olecranon process and does not require stretching.

Although the forearm tends to be a less common site of major fat deposition in comparison with other parts of the body, the divisors based on mid-forearm circumference may predict falsely elevated flap widths in obese patients with disproportionately large forearms. In such cases, the means in Table 1 should be considered if the predicted values appear greater than expected.

Adequate coverage can often be obtained from the FCU flap without complete dissection to the neurovascular pedicle due to its long, ribbon-like shape. Although we have not encountered flap necrosis due to kinking of the pedicle, we caution against undue longitudinal tension on the pedicle to obtain extra length from the flap. Finally, although we used 3 fascial incisions to standardize our results, it is possible that more extensive pie-crusting could widen the flap even further.

REFERENCES

1. Bunkis J, Ryu RK, Walton RL, Epstein LI, Vasconez LO. Fasciocutaneous flap coverage for periolecranon defects. Ann Plast Surg 1985;14:361–370.
2. Rubayi S, Kiyono Y. Flap surgery to cover olecranon pressure ulcers in spinal cord injury patients. Plast Reconstr Surg 2001;107:1473–1481.
3. Hwang K, Han JY, Chung IH. Topographical anatomy of the anconeus muscle for use as a free flap. J Reconstr Microsurg 2004;20:631–636.
4. Schmidt CC, Kohut GN, Greenberg JA, Kann SE, Idler RS, Kiefhaber TR. The anconeus muscle flap: its anatomy and clinical application. J Hand Surg 1999;24A:359–369.
5. Lalikos JF, Fudem GM. Brachioradialis musculocutaneous flap closure of the elbow utilizing a distal skin island: a case report. Ann Plast Surg 1997;39:201–204.
6. Ohtsuka H, Imagawa S. Reconstruction of a posterior defect of the elbow joint using an extensor carpi radialis longus myocutaneous flap: case report. Br J Plast Surg 1985;38:238–240.
7. Mathes SJ, Nahai F. Clinical applications for muscle and musculocutaneous flaps. St. Louis, MO: Mosby, 1982:631–635.
8. Meals RA. The use of a flexor carpi ulnaris muscle flap in the treatment of an infected nonunion of the proximal ulna. A case report. Clin Orthop Relat Res 1989;240:168–172.
9. Roukoz S. Musculocutaneous flexor carpi ulnaris flap for reconstruction of posterior cutaneotricipital defects of the elbow. Plast Reconstr Surg 2003;111:330–335.
10. Parry SW, Ward JW, Mathes SJ. Vascular anatomy of the upper extremity muscles. Plast Reconstr Surg 1988;81:358–365.
11. Lim AY, Kumar VP, Pereira BP, Hua J. Independent function in a tendon transfer of the split flexor carpi ulnaris. Plast Reconstr Surg 1999;104:1739–1741; discussion 1742–1733.
12. Lim AY, Kumar VP, Sebastin SJ, Kapickis M. Split flexor carpi ulnaris transfer: a new functioning free muscle transfer with independent dual function. Plast Reconstr Surg 2006;117:1927–1932.
13. Lingaraj K, Lim AY, Puhaindran ME, Kumar PV. Case report: the split flexor carpi ulnaris as a local muscle flap. Clin Orthop Relat Res 2007;455:262–266.
14. Lim AY, Kumar VP, Hua J, Pereira BP, Pho RW. The neuromuscular compartments of the flexor carpi ulnaris. Plast Reconstr Surg 1999;103:1046–1051; quiz 1052; discussion 1053.
15. Jawad AS, Harrison DH. The island sensate ulnar artery flap for reconstruction around the elbow. Br J Plast Surg 1990;43:695–698.
16. Culbertson JH, Mutimer K. The reverse lateral upper arm flap for elbow coverage. Ann Plast Surg 1987;18:62–68.
17. Thornton JW, Stevenson TR, VanderKolk CA. Osteoradionecrosis of the olecranon: treatment by radial forearm flap. Plast Reconstr Surg 1987;80:833–835.
18. Garcia-Porrua C, Gonzalez-Gay MA, Ibanez D, Garcia-Pais MJ. The clinical spectrum of severe septic bursitis in northwestern Spain: a 10 year study. J Rheumatol 1999;26:663–667.
19. Raddatz DA, Hoffman GS, Franck WA. Septic bursitis: presentation, treatment and prognosis. J Rheumatol 1987;14:1160–1163.
20. Swanson E, Boyd JB, Manktelow RT. The radial forearm flap: reconstructive applications and donor-site defects in 35 consecutive patients. Plast Reconstr Surg 1990;85:258–266.
21. Timmons MJ. The vascular basis of the radial forearm flap. Plast Reconstr Surg 1986;77:80–92.
22. Choudry UH, Moran SL, Li S, Khan S. Soft-tissue coverage of the elbow: an outcome analysis and reconstructive algorithm. Plast Reconstr Surg 2007;119:1852–1857.
23. Stevanovic M, Sharpe F, Itamura JM. Treatment of soft tissue problems about the elbow. Clin Orthop Relat Res 2000;370:127–137.
24. Hollinshead WH. In: Hollinshead WH, ed. Anatomy for surgeons. New York: Harper and Row, 1982:358–395.
25. Boyes JH. Tendon transfers for radial nerve palsy. Bull Hosp Jt Dis 1960;21:97–105.
26. Stevanovic MV, Sharpe F, Pederson WC. Coverage of the elbow. In: Green DP, Hotchkiss RN, Pederson WC, Wolfe SW, eds. Operative hand surgery. 5th ed. New York: Churchill Livingstone, 2005:1704–1714.
27. Raskin KB, Wilgis EF. Flexor carpi ulnaris transfer for radial nerve palsy: functional testing of long-term results. J Hand Surg 1995;20A:737–742.
28. Lim AY, Pereira BP, Kumar VP, De Coninck C, Taki C, Baudet J, et al. Intramuscular innervation of upper-limb skeletal muscles. Muscle Nerve 2004;29:523–530.
29. Pereira BP, Prem Kumar V, Lim AY, Tan JA, Tan BL. Properties of the two neuromuscular compartments in a split bipennate muscle. J Orthop Res 2004;22:1325–1330.