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Epimysium and Perimysium in Suturing in Skeletal Muscle Lacerations

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Background: Direct muscle belly trauma is common. Selecting optimal methods for surgical repair of muscle disruption is difficult because reliable methods have not been established. Suturing tendon offers strong repairs, but epimysium and perimysium, the connective tissues that coalesce to form tendons, offer unknown repair strength. The purpose of this study was to compare biomechanical properties of repaired muscle in transected muscle bellies with epimysium and perimysium.

Methods: The authors surgically repaired with figure-eight stitches in both epimysium and perimysium groups. Individual stitches were placed in lacerated quadriceps bellies from a euthanized pig and were tensioned on a biomechanical machine. Maximum loads and strains were measured, and failure mechanisms were recorded.

Results: Loads and strains for repairs with epimysium were higher than those for repairs with perimysium. Failure mechanisms were significantly different between groups.

Conclusion: These data showed that epimysium incorporation into suturing improves capacity to bear forces compared with perimysium incorporation.

Key Words: Repair, Suture, Laceration, Surgery, Trauma.

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Usually, muscle trauma without muscle disruption is treated with rest, ice, compression, and elevation, but severe muscle injury may indicate the need for surgical repair.[1,2] Observations of superior outcomes in cases of muscle transections treated surgically in both animal and human studies have challenged some of the traditional indications for nonoperative repair.[3–8] However, repair of muscle lacerations without tendon involvement is technically demanding, and the likelihood of clinical failure is high.[9,10] Early clinical results of muscle laceration repair hinge on how well sutured muscle repair constructs bear loading, but there has been little study on techniques of muscle belly suturing.[11] Improved understanding of failure mechanisms and knowledge of the rates of failure for different methods of repair is important to the development of optimal repair techniques. Reliable repair techniques are needed with high initial capacity to bear loads because animal data indicate that early mobilization prevents the marked loss of tensile properties of immobilized muscles compared with prolonged immobilization.[12,13] Optimal suturing of muscles may permit early rehabilitation with a low risk of rerupture or stitch pullout.

Skeletal muscle is organized by its connective tissue components with epimysium surrounding the muscle as a connective tissue sheath, perimysium surrounding bundles of myofascicles, and endomysium surrounding myocytes.[14] In surgical practice, epimysium and myofibers are often untidy in muscle transections.[11,15] Clinical recommendations include debridement or dissection as good ideas to locate connective tissues such as tendinous extensions within muscle to gain an optimal repair as opposed to repair *in situ*.[11,15,16] We suspected that surgical disruption of otherwise healthy muscle tissue may interfere with muscle healing. Also, because epimysium is thicker than perimysium,[17,18] we hypothesized that muscle bellies with epimysium could hold stitches better than muscle bellies with perimysium.

As part of an ongoing series of clinical and laboratory studies by our group, a biomechanical study was designed to compare epimysium incorporation versus perimysium incorporation in sutured muscle bellies.

MATERIALS AND METHODS

An immature female Yorkshire cross pig weighing approximately 40 kg was acquired. The animal was maintained in an accredited facility and cared for in strict accordance with the 1996 *Guide for the Care and Use of Laboratory Animals*. The cadaver limb was obtained at the completion of a protocol approved by the animal care and use committee, and the current study was approved by the institutional review board.

Preparation

The limb was refrigerated at 4°C for 44 hours. The quadriceps femoris muscle was dissected, the compartmental

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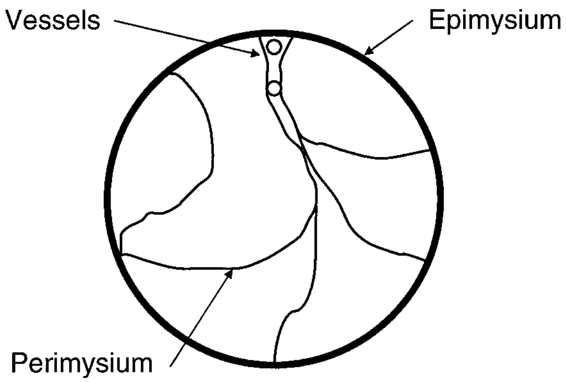

Fig. 1. *Diagram of cross section of skeletal muscle with epimysium and perimysium. The diagram represents an axial cross section of a muscle belly, with two types of connective tissues shown. The connective tissues include the outer sheath, epimysium, on the surface (*thick circumferential circle*). The perimysium (*fine lines*) includes fibrous septae that divide myofibers into grouped fascicles and carry larger vessels (*small circles*) into the inner muscle. Only the larger septae of perimysium are shown as used in the current study.*

fascia was removed, and care was used to preserve the epimysium and perimysium. Muscle belly lacerations were made in areas where no tendon was present, and saline was used to moisten specimens during testing. For the epimysium group, sutures were placed about the edge of the lacerations as is done in clinical practice for surgical repair with figure-eight stitches with metric size 5, braided polyester suture. A stitch was placed at the tendon end of the muscle using a running interlocked technique, and then the sutured specimen was loaded onto a biomechanical testing machine. Perimysium was exposed by removing epimysium and myofibers, and perimysium areas of the specimen were prepared in the same fashion as the epimysium group (Fig. 1).

Study Design

A biomechanical testing protocol was designed for measuring the passive biomechanical properties of sutured muscle belly lacerations. Two groups were tested; the groups were muscle areas with epimysium and muscle areas with perimysium and no epimysium. The parameters compared were maximum load, strain at maximum load, and failure mode. The epimysium repair was used in 31 tests, and the perimysium repair was used in 25 tests.

Biomechanical Testing

A materials testing machine (model 8521S; Instron Corporation, Canton, Mass) was used in a uniaxial set up (Fig. 2). Under position control using a 0.1-kN load cell, the servohydraulic tester applied tension in the long, anatomic axis of the muscle organ, and the stitch and tendon sutures were held in standard grips with leather facing. The modeling tested the passive properties of the sutured muscle belly in approximation of the clinical situation.[7] The sutured muscle was preloaded minimally with 5 to 8 N to remove slack immediately before testing. Stitched muscles were loaded longitudinally at an elongation rate of 25 mm/min until failure.

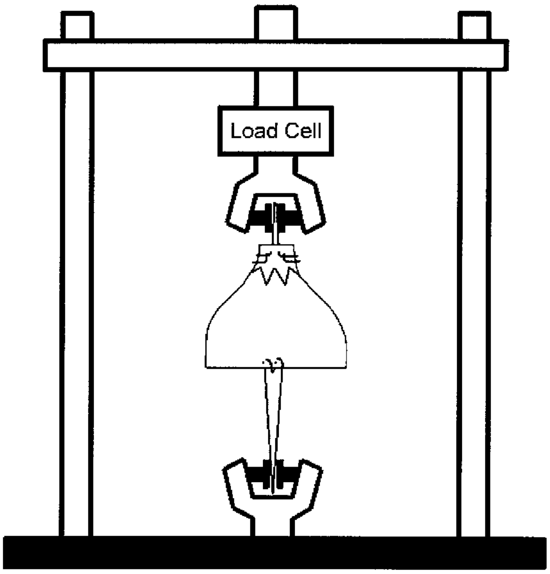

Fig. 2. *Testing setup of materials testing system with connected specimen. The tester includes the base platform, two uprights, the upper crossbar, and two grips. The load cell is* labeled*, and the grip pads are* black*. The figure-eight suture is gripped below, and the tendon suture is gripped above. The muscle specimen is a half belly transected in the middle.*

Data Analysis

Series IX software (Instron Corporation) was used for data collection, and the system recorded the maximum load in newtons and the strain at maximum load in millimeters per millimeter expressed as a percent. Further, the failure mode was observed directly and recorded. Two failure modes were defined. Suture tear-out occurred when sutures pulled out longitudinally from the muscle. Avulsion was the failure mode when the muscle failed transversely and the sutured portion of muscle was removed as the suture pulled out of the muscle.

Independent sample *t* tests were used as the test statistic for loads and strains, and Levene's test was used for assessing equality of variances. For mechanism of failure analysis, a 2 × 2 contingency test was used with Fisher's exact test because of the small sample sizes. A *p* value of less than 0.05 was considered significant. SPSS software (version 11.5; SPSS Inc., Chicago, Ill) was used for statistical analysis.

RESULTS

The mean maximum load for repairs with epimysium was 30.4 N, whereas that for repairs with perimysium was 19.2 N (Table 1 and Fig. 3). The difference between groups was significant ($p < 0.001$).

Table 1 Biomechanical Data Summary of Mean Stitch Performance in Muscle Bellies[a]

	Epimysium	Perimysium	p Value
Maximum load (N)	30.4 ± 11.9	19.2 ± 4.6	<0.001
Strain (mm/mm × 100%)	10.6 ± 3.6	7.5 ± 2.7	0.001
Number of stitches tested	31	25	

[a] Surgical repairs of muscle bellies incorporated epimysium or perimysium. Load values are expressed in newtons (N). Strain values are expressed as millimeters per millimeter in a percentage. Both load and strain means were significantly different between groups.

The mean strain at maximum load for repairs with epimysium was 10.6%, whereas that for repairs with perimysium and without epimysium was 7.5% (Table 1 and Fig. 4). The difference between groups was significant ($p = 0.001$).

The failure mechanisms were not different between groups ($p = 1.000$). One repair stitch with epimysium avulsed the sutured portion of the muscle, whereas 30 sutures failed by longitudinal tear-out from the muscle. One perimysium repair stitch avulsed muscle, whereas 24 sutures tore out longitudinally. The weakest element was the sutured portion of the muscle in each specimen and test.

DISCUSSION

The current study demonstrates that epimysium incorporation permitted stitches to load muscle better than perimysium incorporation. The biomechanical properties of muscle repair differ significantly by suturing different connective tissues.

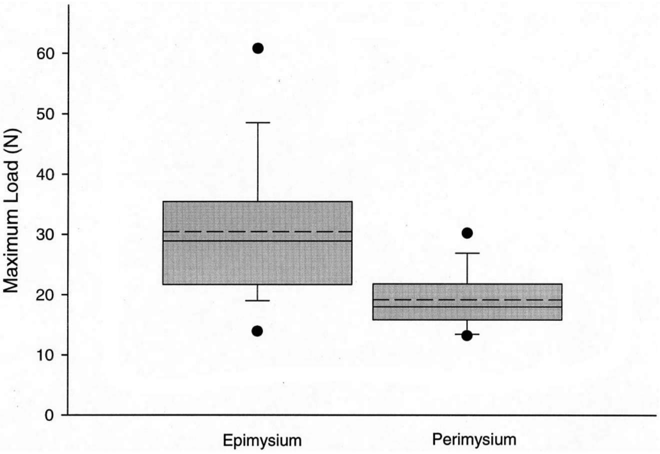

Fig. 3. *Maximum loads for sutured muscle bellies. The* gray box plots *express a range from the 25th to 75th percent confidence limits. The mean is the* dashed line*, and the median is the* solid line within the box. *The* error bars *express a range from the 10th to 90th percent confidence limits. The* dots *are the 5th to 95th percent confidence limits. Loads are expressed in newtons. The mean maximum loads are significantly different between groups (*$p < 0.001$*). The epimysium repair was used in 31 tests, and the perimysium repair was used in 25 tests.*

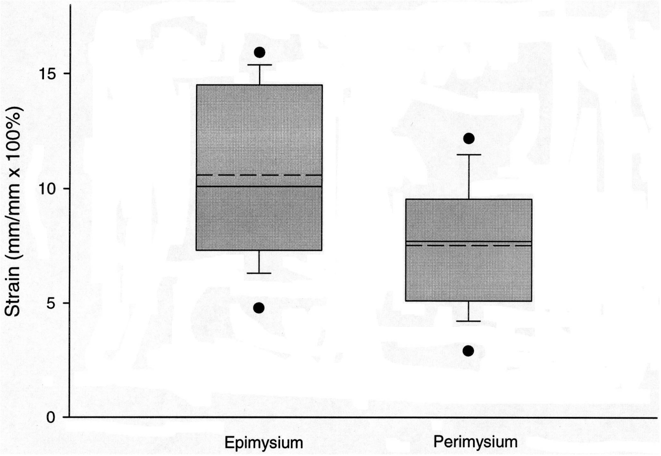

Fig. 4. *Strain data of stitches in muscle with epimysium or perimysium incorporation. The* gray box plots *express a range from the 25th to 75th percent confidence limits. The mean is the* dashed line*, and the median is the* solid line within the box. *The* error bars *express a range from the 10th to 90th percent confidence limits. The* dots *are the 5th to 95th percent confidence limits. The mean strains are significantly different between groups (*$p = 0.001$*). The epimysium repair was used in 31 tests, and the perimysium repair was used in 25 tests.*

The finding of the current study pertains to surgical care of muscle disruptions and the handling of soft tissues. The quantity of fibrous tissue is greater in the epimysium than in the perimysium because the epimysium is thicker and made of two fibrous layers.[17] If the maximum load of stitching is related to the quantity of fibrous tissue, suturing both layers of the epimysium is likely better than incorporating only one layer. Because both layers of epimysium move with the muscle, the sliding properties of the muscle-fascia interface are likely disturbed little with a repair incorporating both layers, but fascia turndown[4] or grafting to the muscle surface in repairs may alter sliding substantially.[19,20]

The finding of the current study adds new knowledge to understanding muscle surgical repair and soft tissue handling. In a key muscle repair case series,[3] investigators changed their surgical technique from figure-eight stitching to use of a tendon graft that acted like a suture material, because the tendon graft went through the epimysium and muscle, similarly to simple suturing. The implication of the change from suturing with suture to suturing with tendon was that the tendon (as suture material) loaded the epimysium better by improved tendon-epimysium contact at the epimysium surface. In a published study, we demonstrated that epimysium incorporation was biomechanically superior to muscle repair without epimysium, and the perimysium repair results of the current study were similar to results of repair without epimysium.[7] If a central issue of muscle repair is improved suture-muscle surface contact, perimysium incorporation would be better than repair without epimysium and perimysium. However, the data do not support this conclusion based on the importance of contact. Comparison of the data from the previous and current studies indicates that contact may be less important than overall loading. Comparison of the previous and current studies indicates that a central issue is how well the suture loads the repaired muscle overall. Passive biomechanical properties of the improved muscle loading under tension is mainly by way of the connective tissue ultrastructure, namely how the stitch loads are dispersed successfully to the muscle overall.[21] Removing myofibers and endomysium decreases the quantity of tissues available for loading in repair. Epimysium incorporation in suturing seems to permit better loading of repaired muscle.

Surgical handling of the delicate epimysium and muscle soft tissues should be atraumatic to limit scarring and further muscle injury.[22] In our experience, we débride clots and transected myofiber ends with irrigation and gentle curetting. More débridement may be indicated if muscle is devitalized. Removing muscle belly tissue necessarily removes endomysium and myofibers and thereby decreases the quantity of connective tissue and the capacity of sutures to load repaired muscle. The delicate epimysium is similar in thickness, appearance, and stiffness to the casing on a sausage because both and are thin, transparent, and handle surgically similarly. Surgical rehearsal with sausages can help residents prepare for the technically demanding exercise of muscle transection repair. Grocery beef and pork cuts with epimysium can be used to simulate clinical laceration repairs to improve soft tissue handling skills, and surgical confidence improves with practice and experience. From our experience, we prefer blunt digital dissection to preserve the epimysium and separate muscle from scar. We prefer DeBakey forceps because they are atraumatic.

In summary, the current study established that incorporation of the epimysium into muscle repair significantly improves the biomechanical properties of sutured muscle bellies when compared with repairs with perimysium.

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REFERENCES

1. Garrett WE Jr, Seaber AV, Boswick J, Urbaniak JR. Recovery of skeletal muscle after laceration and repair. *J Hand Surg [Am].* 1984; 9:683–692.
2. Jarvinen TAH, Kaarianen M. Muscle strain injuries. *Curr Opin Rheum.* 2000;12:155–161.
3. Botte MJ, Gelberman RH, Smith DG, Silver MA, Gellman H. Repair of severe muscle belly lacerations using a tendon graft. *J Hand Surg [Am].* 1987;12:406–412.
4. Heckman JD, Levine MI. Traumatic closed transection of the biceps brachii in the military parachutist. *J Bone Joint Surg [Am].* 1978; 60:369–372.
5. Chien SH, Chen SK, Lin SY, Chen SS, Wu HS. Repair method and healing of skeletal muscle injury [in Chinese]. *Gaoxiong Yi Xue Ke Xue Za Zhi.* 1991;7:481–488.
6. Urabe T. An experimental study on recovery of lacerated muscles after repair [in Japanese]. *Nippon Seikeigeka Gakkai Zasshi.* 1988; 62:415–425.
7. Kragh JF Jr, Basamania CJ. Surgical repair of acute traumatic closed transection of the biceps brachii. *J Bone Joint Surg [Am].* 2002; 84:992–998.
8. Menetrey J, Kasemkijwattana C, Fu FH, Moreland MS, Huard J. Suturing versus immobilization of a muscle laceration: a morphological and functional study in a mouse model. *Am J Sports Med.* 1999;27:222–229.
9. Faibisoff B, Daniel RK. Management of severe forearm injuries. *Surg Clin North Am.* 1981;61:287–301.
10. Phillips LG, Heggers JP. Layered closure of lacerations. *Postgrad Med.* 1988;83:142–148.
11. Chammout MO, Skinner HB. The clinical anatomy of commonly injured muscle bellies. *J Trauma.* 1986;26:549–552.
12. Jozsa L, Kannus P, Thoring J, Reffy A, Jarvinen M, Kvist M. The effect of tenotomy and immobilisation on intramuscular connective tissue. *J Bone Joint Surg [Br].* 1990;72:293–297.
13. Jarvinen MJ, Lehto MUK. The effects of early mobilisation and immobilisation on the healing process following muscle injuries. *Sports Med.* 1993;15:78–89.
14. Garrett WE Jr, Best TM. Anatomy, physiology, and mechanics of skeletal muscle. In: Simon SR, ed. *Orthopaedic Basic Science.* American Academy of Orthopaedic Surgeons; 1994:89–91.
15. Peacock EE Jr, Van Winkle W Jr. *Wound Repair.* 2nd ed. Philadelphia, Pa: WB Saunders; 1984.
16. Justis EJ Jr. Affections of muscles, tendons, and associated structures. In: Edmondson AS, Crenshaw AH, eds. *Campbell's Operative Orthopaedics.* 6th ed. St. Louis, Mo: Mosby; 1980:1385–1395.
17. Nishimura T, Hattori A, Takahashi K. Ultrastructure of the intramuscular connective tissue in bovine skeletal muscle: a demonstration using cell-maceration/scanning electron microscope method. *Acta Anatomica.* 1994;151:250–257.
18. Sakamoto Y. Histological features of endomysium, perimysium, and epimysium in rat lateral pterygoid muscle. *J Morphol.* 1996; 227:113–119.
19. Kawamata S, Ozawa J, Masakazu H, Kurose T. Structure of the rat subcutaneous connective tissue in relation to its sliding mechanism. *Acta Histol Cytol.* 2003;66:273–279.
20. McCombe D, Brown T, Slavin J, Morrison WA. The histochemical structure of the deep fascia and its structural response to surgery. *J Hand Surg [B].* 2001;26:89–97.
21. Gajdosik RL. Passive extensibility of skeletal muscle: review of the literature with clinical implications. *Clin Biomech.* 2001; 16:87–101.
22. Dyer JA, Lee DA. *Atlas of Extraocular Muscle Surgery.* 2nd ed. New York, NY: Praeger; 1984.