

# Suturing of lacerations of skeletal muscle

J. F. Kragh Jr,  
S. J. Svoboda,  
J. C. Wenke,  
J. A. Ward,  
T. J. Walters

From Brooke Army  
Medical Centre, Fort  
Sam Houston, Texas,  
USA

**Our aim was to compare the biomechanical properties of suturing methods to determine a better method for the repair of lacerated skeletal muscle.**

**We tested Kessler stitches and the combination of Mason-Allen and perimeter stitches. Individual stitches were placed in the muscle belly of quadriceps femoris from a pig cadaver and were tensioned mechanically. The maximum loads and strains were measured and failure modes recorded. The mean load and strain for the Kessler stitches were significantly less than those for combination stitches. All five Kessler stitches tore out longitudinally from the muscle. All five combination stitches did not fail but successfully elongated.**

**Our study has shown that the better method of repair for suturing muscle is the use of combination stitches.**

■ J. F. Kragh Jr, MD,  
Orthopaedic Surgeon  
■ S. J. Svoboda, MD,  
Orthopaedic Surgeon  
Department of Orthopaedics  
and Rehabilitation  
■ J. A. Ward, PhD, Research  
Physiologist  
Department of Clinical  
Investigation  
Brooke Army Medical Center,  
MCHE-DOR Room 129-5,  
Building 3600, 3851 Roger  
Brooke Drive, Fort Sam  
Houston, Texas 78234-6200,  
USA.

■ J. C. Wenke, PhD,  
Research Physiologist  
■ T. J. Walters, PhD,  
Research Physiologist  
US Army Institute of Surgical  
Research, Bone and Soft  
Tissue Research Program,  
3400 Rawley E. Chambers  
Avenue, Room 291-1  
Building 3611, Fort Sam  
Houston, Texas 78234-6315,  
USA.

Correspondence should be  
sent to Dr J. F. Kragh; e-mail:  
john.kragh@  
amedd.army.mil

©2005 British Editorial  
Society of Bone and  
Joint Surgery  
doi:10.1302/0301-620X.87B9.  
15728 \$2.00

*J Bone Joint Surg [Br]*  
2005;87-B:1303-5.  
Received 15 June 2004;  
Accepted after revision  
15 March 2005

Direct muscle trauma is common<sup>1-3</sup> and discontinuity of muscle bellies is an indication for surgery. However, the best suturing technique is not known. Muscle bellies are difficult to repair successfully because the sutures pull out.<sup>4,5</sup> Some authors have reported healing after repair.<sup>6-12</sup> These differences may be partly explained by the variation in suturing techniques, of which many have been recommended<sup>6-12</sup> but few have been compared. For example, a modified Kessler suture, with 5-0 Mersilene, was found to be better than either simple suturing with 2-0 Dexon or simple suturing with a tendon graft.<sup>6</sup> We have previously reported a clinical series of transections of biceps brachii repaired by a combination stitching technique, with a modified Mason-Allen stitch around a perimeter stitch.<sup>8</sup> The combination stitches worked well.

Our aim, therefore, was to compare the maximum loads, strains, and failure modes of muscle bellies sutured with Kessler stitches with those of muscles sutured with combination stitches.

## Materials and Methods

A limb was obtained from an immature female Yorkshire-cross pig weighing approximately 40 kg which had been killed in the course of another study. The experiment was approved by the Animal Care and Use Committee and the present study was approved by the institutional review board.

In a pilot study, we selected the best two suturing methods from several methods in-

cluding a simple stitch,<sup>10</sup> a running simple (epimysium-based, non-core) stitch, a figure-of-eight stitch,<sup>13</sup> a modified Kessler stitch,<sup>6</sup> a vertical mattress stitch,<sup>14</sup> a horizontal mattress stitch (core), a horizontal mattress stitch (inverted, epimysium-based, non-core), a double right-angle stitch<sup>15</sup> and a combination (modified Mason Allen<sup>16</sup> and perimeter) stitch.<sup>8</sup>

The two methods with the highest maximum loads in our pilot study were the Kessler stitch and the combination stitch (Mason-Allen stitch around a perimeter stitch) methods. The performance of the Kessler stitch confirmed that of previous work.<sup>6</sup>

**Design of the study.** A biomechanical protocol was designed for measuring the passive performance of sutures in lacerations of the muscle belly. We compared individual Kessler stitches and combination stitches. There were five observations in each group. We measured the maximum load, the strain at maximum load and the failure mode.

The limb was refrigerated at -4°C for 43 hours. Quadriceps femoris was dissected from the compartmental fascia taking care to preserve the epimysium. A transverse laceration was made across the belly in an area where no tendon was present. Saline was used to moisten the specimens during testing. For the Kessler stitch group, the sutures were placed around the edge of the laceration using metric size 2 braided polyester sutures (Deknatel, Fall River, Massachusetts) (Fig. 1).<sup>6</sup> Different parts of the same specimen were used for the experiment

| Report Documentation Page                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                   |                                    |                                             | Form Approved<br>OMB No. 0704-0188          |                                    |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------|------------------------------------|---------------------------------------------|---------------------------------------------|------------------------------------|
| Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. |                                   |                                    |                                             |                                             |                                    |
| 1. REPORT DATE<br><b>01 SEP 2005</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                   | 2. REPORT TYPE<br><b>N/A</b>       |                                             | 3. DATES COVERED<br><b>-</b>                |                                    |
| 4. TITLE AND SUBTITLE<br><b>Suturing of lacerations of skeletal muscle.</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                   |                                    |                                             | 5a. CONTRACT NUMBER                         |                                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                   |                                    |                                             | 5b. GRANT NUMBER                            |                                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                   |                                    |                                             | 5c. PROGRAM ELEMENT NUMBER                  |                                    |
| 6. AUTHOR(S)<br><b>Kragh J. F. Jr., Svoboda S. J., Wenke J. C., Ward J. A., Walters T. J.,</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                   |                                    |                                             | 5d. PROJECT NUMBER                          |                                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                   |                                    |                                             | 5e. TASK NUMBER                             |                                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                   |                                    |                                             | 5f. WORK UNIT NUMBER                        |                                    |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br><b>United States Army Institute of Surgical Research, JBSA FOrt Sam Houston, TX 78234</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                   |                                    |                                             | 8. PERFORMING ORGANIZATION<br>REPORT NUMBER |                                    |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                   |                                    |                                             | 10. SPONSOR/MONITOR'S ACRONYM(S)            |                                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                   |                                    |                                             | 11. SPONSOR/MONITOR'S REPORT<br>NUMBER(S)   |                                    |
| 12. DISTRIBUTION/AVAILABILITY STATEMENT<br><b>Approved for public release, distribution unlimited</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                   |                                    |                                             |                                             |                                    |
| 13. SUPPLEMENTARY NOTES                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                   |                                    |                                             |                                             |                                    |
| 14. ABSTRACT                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                   |                                    |                                             |                                             |                                    |
| 15. SUBJECT TERMS                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                   |                                    |                                             |                                             |                                    |
| 16. SECURITY CLASSIFICATION OF:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                   |                                    | 17. LIMITATION OF<br>ABSTRACT<br><b>SAR</b> | 18. NUMBER<br>OF PAGES<br><b>3</b>          | 19a. NAME OF<br>RESPONSIBLE PERSON |
| a REPORT<br><b>unclassified</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | b ABSTRACT<br><b>unclassified</b> | c THIS PAGE<br><b>unclassified</b> |                                             |                                             |                                    |

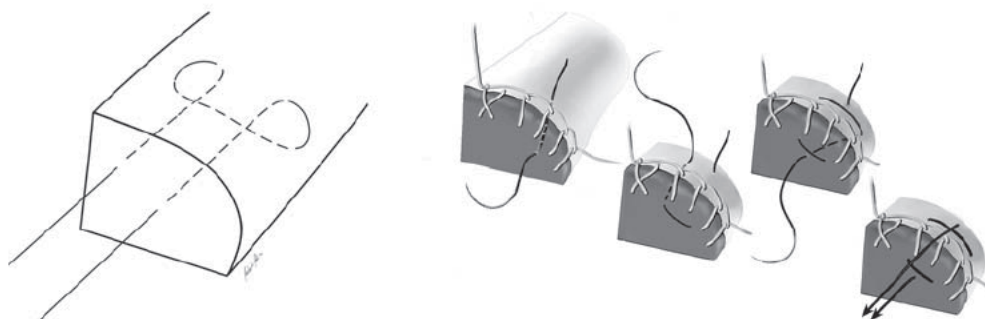


Fig. 1

Diagram of the stitches tested showing a) the Kessler stitch and b) the combination stitch.

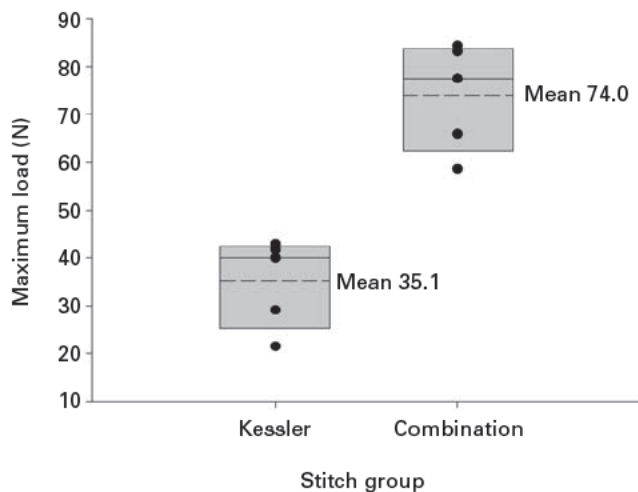


Fig. 2

Maximum load data for the Kessler and combination stitches in muscle repair. The box plots have the 25th and 75th percentage confidence limits as the lower and upper borders, respectively. The mean is the dashed line and the median is the solid line. The dots are the data points. The difference between the mean maximum loads is significant ( $p < 0.001$ ).

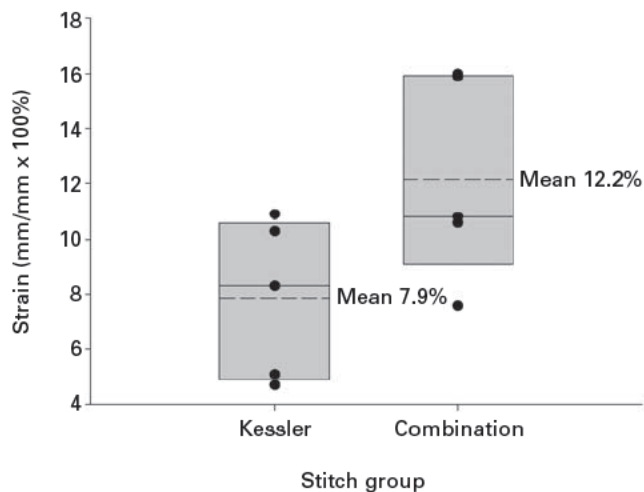


Fig. 3

Strain data for the Kessler and combination stitches in muscle repair. The box plots have the 25th and 75th percentage confidence limits as the lower and upper borders, respectively. The mean is the dashed line and the median is the solid line. The dots are the data points. The difference between the mean strains at maximum load is significant ( $p = 0.036$ ).

including the collection of the pilot data. They were spaced around the epimysium so that they were separate. Modified Mason-Allen stitches were supported by a running interlocking stitch along the border of the epimysium with figure-of-eight knots at one end (Fig. 1).<sup>8</sup> The same suture material was used for all the stitches.

**Testing of specimens.** A servohydraulic testing machine (model 8521S; Instron Corporation, Canton, Massachusetts) was used in a uniaxial configuration. The construct was preloaded with 5 to 8 N, in the anatomical axis of the muscle, to remove the slack before testing. It was loaded at an elongation rate of 25 mm per minute until failure.

**Analysis of data.** Data collection software (Series IX, Instron Corporation) recorded the load and strain data as the biomechanical parameters of the performance of the stitches. Maximum load was expressed in newtons and the mm expressed as a percentage. The failure mode was observed directly and recorded.

**Statistical analysis.** Independent sample *t*-tests were used for loads and strains and Levene's test for assessing the quality of variance. The Kolmogorov-Smirnov test confirmed that there was no significant difference between the observed distributions and a normal distribution ( $p > 0.05$ ) and, therefore, the use of independent sample *t*-tests was justified. For analysing the mechanism of failure, a 2 x 2 contingency test was used with Fisher's exact test because of the small sample sizes. A *p* value  $< 0.05$  was considered to be significant. SPSS (version 11.5; SPSS Inc, Chicago, Illinois) and Sigmaplot (version 9.0; Systat Software, Point Richmond, California) were used for statistical analysis.

## Results

**Maximum load.** The difference between the mean of the Kessler and combination stitches was significant ( $p < 0.001$ ; Fig. 2). The mean maximum load was 35.1 N (SD 9.4) for

Kessler stitches and 74.0 N (SD 11.3) for combination stitches.

**Strain at maximum load.** The difference between the means was significant ( $p = 0.036$ ); Fig. 3). The mean strain at maximum load was 7.9% (SD 2.9) for Kessler stitches and 12.2% (SD 3.7) for combination stitches.

**Failure mode.** There was a significant difference in the failure modes between the groups ( $p = 0.008$ ). All five Kessler stitches tore out from the muscle. No combination stitch failed since each elongated successfully and reached the maximum preset displacement of 35 mm.

## Discussion

Our study showed that the maximum loads for combination stitches were more than double those for Kessler. The strain at maximum load and the failure mode were better with the combination stitches.

The suture usually pulls out of the muscle, but in our study we found that the muscle did not fail before reaching the maximum displacement of 35 mm. Overall, the combination of a core stitch (Mason-Allen) and an epimysium-based stitch (perimeter stitch) loaded the muscle better than the core stitch alone (Kessler stitch).

The strength of our study is the comparison of the properties of the initial stitch in muscle lacerations. We are aware that the loads and strains would be higher if our method had allowed further elongation when the results for the combination stitch may have been even better. Our study complements a clinical report in which the combination stitch technique showed good outcomes.<sup>8</sup>

The weakness of our study is the limited scope of the model. The effect of cellular healing cannot be considered in cadaver specimens. Tendon repairs have been found to be weakest about 21 days after repair.<sup>17</sup> We did not look at issues such as the size of the suture, the material, the strand number or tendon grafting.<sup>13</sup> Cyclical loading of a repair of the two half bellies was not studied. The sample sizes were small, but using one muscle for testing allowed assessment

of the performance of the stitches to be made without inter-muscular variability.

The authors would like to thank Michael A. Dubick PhD and Jill L. Sondeen PhD for their assistance with specimen collection, Amy W. Newland for aid in writing, Mr Roberto Rios of Brooke Army Medical Center and Marsha J. Dohrman for the illustrations. We would like to attribute creation of the combination stitch to Carl J. Basamania.

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

## References

1. **Praemer A, Furner S, Rice DP.** *Musculoskeletal conditions in the united states.* Park Ridge, Illinois: American Academy of Orthopaedic Surgeons, 1992.
2. **Zarins B, Cuiello JV.** Acute muscle and tendon injuries in athletes. *Clin Sports Med* 1983;2:167-82.
3. **Garrett WE Jr.** Injuries to the muscle-tendon unit. *Instr Course Lect* 1988;37:275-82.
4. **Faibisoff B, Daniel RK.** Management of severe forearm injuries. *Surg Clin North Am* 1981;61:287-301.
5. **Phillips LG, Hegggers JP.** Layered closure of lacerations. *Postgrad Med* 1988;83:142-8.
6. **Chien SH, Chen SK, Lin SY, Chen SS, Wu HS.** Repair method and healing of skeletal muscle injury. *Gaoxiong Yi Xue Ke Xue Za Zhi* 1991;7:481-8 (in Chinese).
7. **Urabe T.** An experiment study on recovery of lacerated muscles after repair. *Nippon Seikeigeka Gakkai Zasshi* 1988;62:415-25 (in Japanese).
8. **Kragh JF Jr, Basamania CJ.** Surgical repair of acute traumatic closed transection of the biceps brachii. *J Bone Joint Surg [Am]* 2002;84-A:992-8.
9. **Menetreg 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;27:222-9.
10. **Mason GA.** Rupture of muscular belly of biceps brachii due to direct violence. *Lancet* 1924;2:273.
11. **Hemingway AE, Herrington L, Blower AL.** Changes in muscle strength and pain in response to surgical repair of posterior abdominal wall disruption followed by rehabilitation. *Br J Sports Med* 2003;37:54-8.
12. **Gilcreest EL.** The common syndrome of rupture, dislocation and elongation of the long head of the biceps brachii. *Surg Gynecol Obstet* 1933;58:322-39.
13. **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;12:406-12.
14. **Eaton-Wells R.** Surgical repair of acute muscle rupture in the racing greyhound. *Veterinary Comparative Orthopaedics Traumatol* 1992;5:18-21.
15. **Heckman JD, Levine MI.** Traumatic closed transection of the biceps brachii in the military parachutist. *J Bone Joint Surg [Am]* 1978;60-A:369-72.
16. **Gerber C, Schneeberger AG, Beck M, Schlegel U.** Mechanical strength of repairs of the rotator cuff. *J Bone Joint Surg [Br]* 1994;76-B:371-80.
17. **Beredjikian PK.** Biologic aspects of flexor tendon laceration and repair. *J Bone Joint Surg [Am]* 2003;85-A:539-50.