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Original Article

Biomechanical evaluation between the modified Mason-Allen stitch and the locked double-tie stitch on the infraspinatus of sheep☆,☆☆

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ABSTRACT

Objectives: To evaluate and compare the *in vitro* biomechanical results from two stitches: the Mason-Allen stitch, as modified by Habermeyer; and the locked double-tie stitch developed at our service, on tendons of the infraspinatus muscle of sheep.

Methods: Twenty tendons from the infraspinatus muscle of sheep were randomly divided into two groups: LDT, on which the locked double-tie stitch was performed; and MA, with the modified Mason-Allen stitch. The evaluation was performed in the mechanics laboratory, using a standard test machine with unidirectional traction, constant velocity of 20 mm per second and a 500 N load cell, without force cycling.

Results: We observed that LDT was superior to MA, for the force needed to form spaces of both 5 mm ($p = 0.01$) and 10 mm ($p = 0.002$) and also for the maximum traction resistance ($p = 0.003$).

Conclusion: We confirmed our hypothesis that LDT stitches are superior to MA stitches from a biomechanical point of view. This is a further stitching option for surgeons, when fragile and poorly vascularized tendons need to be sutured, and it improves the quality of fixation without increasing the "strangulation" and, consequently, the ischemic area.

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Avaliação biomecânica de ovinos entre o ponto Mason-Allen modificado e o ponto com duplo-laço bloqueado em infraespinal

RESUMO

Objetivos: Avaliar e comparar os resultados biomecânicos *in vitro* de dois pontos: o Mason-Allen modificado por Habermeyer e o ponto duplo-laço bloqueado (DLB), desenvolvido no nosso serviço em tendões de músculos infraespinais de ovinos.
Métodos: Vinte tendões do músculo infraespinal de ovinos foram divididos aleatoriamente em dois grupos: o DLB, no qual foi confeccionado o ponto duplo-laço bloqueado; e o MA, com o ponto Mason-Allen modificado. A avaliação foi feita no laboratório de mecânica, com uma máquina de teste padrão, de tração unidirecional, com velocidade constante de 20 mm por segundo, com uma célula de carga de 500 N, sem ciclagem de força.
Resultados: Evidenciamos uma superioridade do DLB sobre o MA, tanto na força necessária para formar 5 mm de espaço (p = 0,01) como 10 mm (p = 0,002) e também na resistência máxima de tração (p = 0,003).
Conclusão: Confirmamos nossa hipótese de que o ponto com DLB é superior ao MA do ponto de vista biomecânico. Essa é mais uma opção de ponto para o cirurgião, quando precisa suturar tendões frágeis e pouco vascularizados, e melhora a qualidade da fixação sem aumentar o "estrangulamento" e, consequentemente, a área isquêmica.

Palavras-chave:
Técnicas de sutura
Ombro
Bainha rotadora

Introduction

Suturing of rotator cuff injuries (RCIs) is one of the biggest challenges for shoulder surgeons. There are high dehiscence rates, especially in relation to extensive injuries, and the incidence can range from 13% to 94% of the cases.[1,2]

The aim of surgical treatment is to mechanically produce a firm and secure suture of the tendon at its insertion site so that healing can take place. The surgical materials used are today highly reliable and for this reason, according to Cummins, the major cause of repair failure is the interface of the suture thread with the tendon.[3] Gerber et al.[4] suggested that the ideal repair should withstand a high traction force during the initial period of fixation, enable formation of the minimum space between the tendon and bone and maintain mechanical stability until healing takes place. The type of stitch used for the suture is a crucial part of the success or failure of the surgical procedure.

Arthroscopic RCI repairs require a refined operative technique and knowledge and skill on the part of the surgeon in order to pass the thread through the tendon. The suturing can be performed using different types of stitches, which were developed to withstand traction forces without undoing the tendon repair.[5] The Mason-Allen stitch is the most resistant type.[4] It can be performed arthroscopically and is then known as the modified Mason-Allen stitch, as described by Scheibel and Habermeyer.[6]

With regard to tendon suturing performed as an open procedure, the technique developed by Krackow et al.[7] is generally recognized as the most resistant and secure method, but it is almost impossible to perform it arthroscopically. Moreover, because it involves stitches that are transverse to the direction of the tendon, it may compromise the vascularization of the tendon and thus the healing of the injury.

Based on the Lasso-Loop stitch described by Lafosse et al.,[8] the senior member of our group (SLC) sought to develop a technique that could be combined with the resistance of the suture developed by Krackow et al.[7] and which could be performed arthroscopically while only minimally compromising the vascularization. This new technique is performed using doubly locked longitudinal stitches, which we have name locked double-tie (LDT) stitches.

In addition to describing the technique for constructing LDT stitches, done on the tendon of the infraspinatus muscle of sheep, we compare it biomechanically with the modified Mason-Allen stitch, which is considered to be the most resistant method performed arthroscopically.[6]

This study using animals was approved by our institution's ethics committee.

Materials and methods

Surgical technique

The LDT stitch is simples, but like all techniques, it needs to be practiced and assistants need to be trained. Use of knotless anchors facilitates construction of these stitches but is not essential. The six steps in making these stitches are as follows:

First: After placing the suture anchor in the appropriate position, using an arthroscopic suturing needle, one of the ends of the thread is passed through the tendon from the articular to the subacromial face, approximately 20 mm medially to the lateral border of the tendon, close to the muscle–tendon transition. The thread should run through the anchor and not be trapped (Fig. 1A).

Second: The length of the thread is equalized and then the suturing needle is used to make another partial passage of

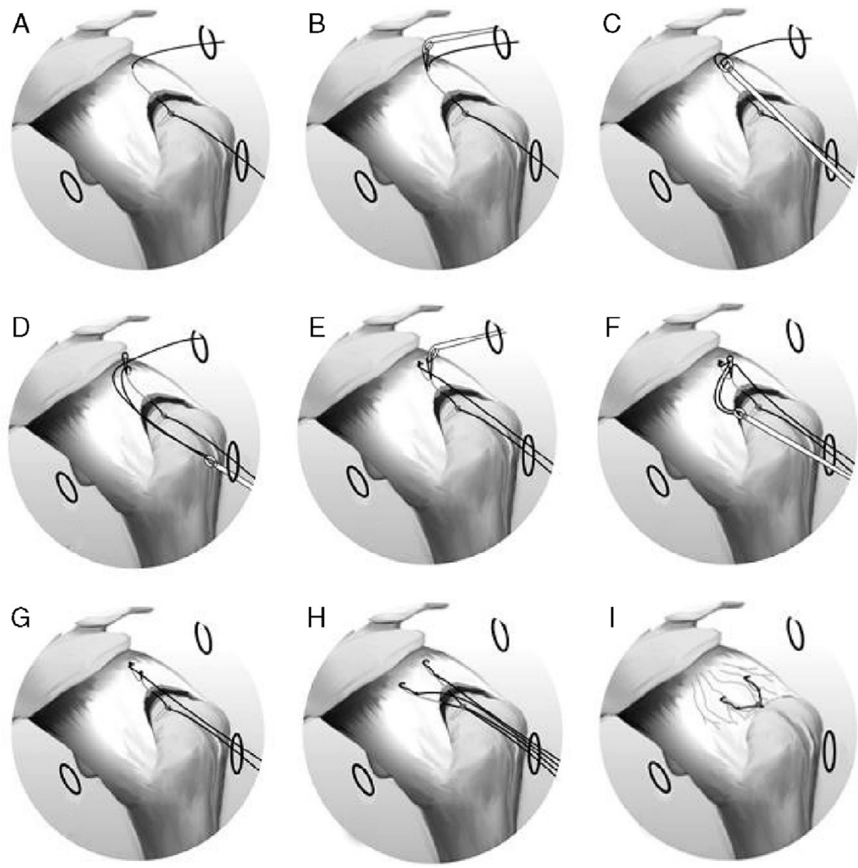

Fig. 1 – Sequence of steps for constructing the locked double-tie stitch. (A) First passage of the suturing thread from the articular face to the subacromial face. (B) Formation of the first loop (subacromial face). (C) Passage of the subacromial thread through the loop that was made previously. (D) Tensioning the lower thread, thus locking the first part of the suture. (E) Formation of the second loop, approximately 10 mm from the lateral extremity of the tendon. (F) Passage of the acromial thread through this second loop. (G) Tensioning of the lower thread, thus locking the second part of the suture. (H) Performing the same stitch with the other thread on the anchor. (I) Final appearance of the stitch, showing how it is parallel to the blood irrigation of the tendon.

the same thread, leaving a loop from the articular face to the subacromial face (Fig. 1B).

Third: The end of the thread that is in the subacromial space is passed through this loop. At this time, the lower thread is tensioned, which thus locks the first part of the suture (Fig. 1C and D).

Fourth: A new loop is made approximately 10 mm from the lateral extremity of the tendon (Fig. 1E).

Fifth: The end of this thread is passed through this new loop (Fig. 1F).

Sixth: The stitch is then tightened using nonslip knots and the lesion is closed (Fig. 1G).

With a suturing anchor loaded with two thread, two stitches can be constructed and the suture resistance can be further increased (Fig. 1H and I).

Biomechanical evaluation

In previous experimental studies, it was established and demonstrated that the tendon of the infraspinatus muscle of sheep has characteristics similar to those of the supraspinatus of the human shoulder and serves as a model for studies on rotator cuff diseases.[9,10]

Twenty tendons of the infraspinatus muscle of male Texel sheep aged 1.5–2 years were used in this study. These were randomly divided into two groups: LDT, in which the stitch described above was constructed (Fig. 2A); and MA, in which the modified Mason-Allen stitch[6] was constructed (Fig. 2B). In removing the tendons from the animals, only the tendon part of the infraspinatus muscle was preserved. Tenotomy was performed on the humeral insertion, without any bone structure continuing to adhere to the tendon. The samples did not undergo any freezing process and were kept in saline solution at −5 °C. Before the stitch was constructed, the thickness and width of the tendons were measured. The stitches were constructed using arthroscopic instruments (Bird-Beak® and Tendon-Grasper®, from Arthrex) and the thread used was Fiber-wire® no. 2 (Arthrex). The proximal extremity of the tendon was to a clamping device and the threads were fixed in a component of a traction device that had an opening through which the threads were passed and tied to a fixed bar, using nonslip stitches and an arthroscopic knot pusher. The sample

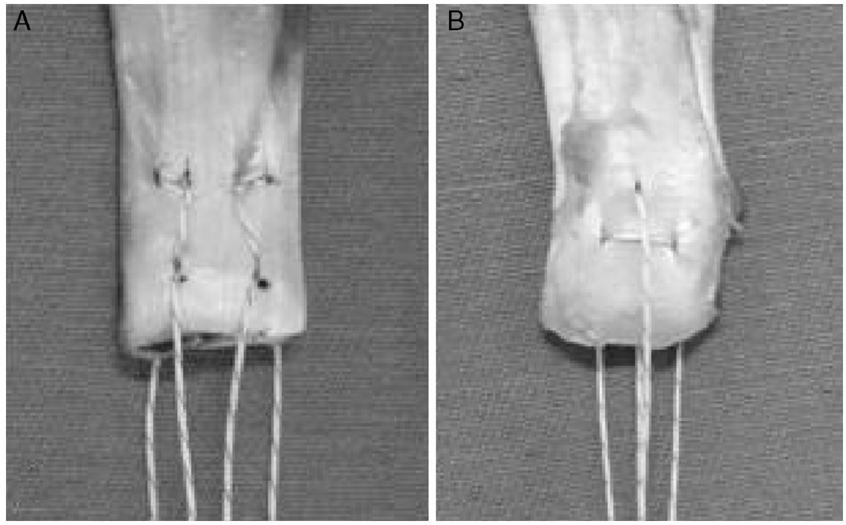

Fig. 2 – (A) Locked double-tie stitch and (B) modified Mason-Allen stitch.

was subjected to an initial load of 30 N for 60 s to pretension the suture. The traction device had a scale marked in millimeters and this was used to observe the force needed to form displacements of 5 mm and 10 mm and the maximum force that the sample withstood. The causes of the failures were also noted (Fig. 3).

The evaluation was done in the mechanics laboratory, using a standard test machine with unidirectional traction (MTS; Qtest model), at a constant velocity of 20 mm per second, with a load cell of 500 N and without cycling of the force applied.

Fig. 3 – Layout of the stitches and test platform.

Statistical assessment

Descriptive analysis was performed in relation to the spaces of 5 mm and 10 mm and the maximum force measured in each type of stitch. After all of the adherences had been checked, their equality of variance was tested for each pair of variables (measured in both types of stitch), by means of the Fisher *F* test.

The Student *t* test was then used on the variables of weight, width and thickness to ascertain the equality between their means, and on the variables of 5 mm space, 10 mm space and maximum force, to investigate whether the means obtained from using the LDT stitch were superior to those obtained from using the MA stitch.

For all the tests, the significance level used was 5%. Thus, the hypotheses in which the descriptive levels (*p*-values) were <0.05 were rejected.

Results

Table 1 presents the mean, standard deviation (SD) and minimum, median and maximum values obtained for each variable and for each type of stitch used.

To compare the 5 mm space, 10 mm space and maximum force of the two groups, an *F* test was firstly performed to collate the variances. The hypothesis that the means for the variables of 5 mm, 10 mm and maximum force in the LDT stitch group were at most equal to the means in the MA stitch group was then tested using the Student *t* test. From this, it was concluded that the means for these variables in the LDT stitch group were superior to those of the MA group, at the significance level of 5% (Figs. 4–6).

Discussion

Competent suturing of RCIs should resist the initial traction force of the tendon, allow as little separation as possible

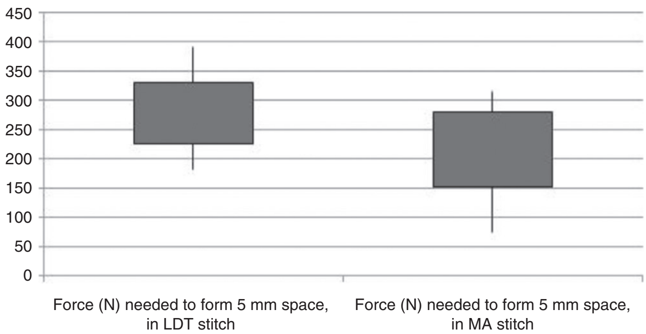

Fig. 4 – Difference in force needed to form a 5 mm space, between the groups.

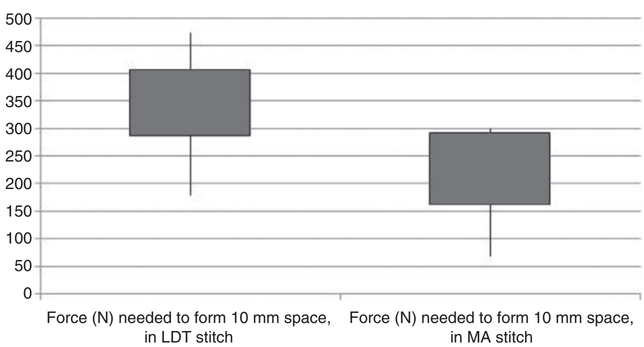

Fig. 5 – Difference in force needed to form a 10 mm space, between the groups.

between the tendon edges and the bone bed and maintain stability until the injury has healed.[4] Through stable and resistant suturing, muscle–tendon–bone union will again be achieved after healing.

After large numbers of cases of repeated tearing had been observed, especially in situations of extensive injury, interest in developing new techniques to improve the results from these operations increased.[11–13] Recent studies have shown that the key point in maintaining these mechanical properties is the interface between the suture and the tendon.[3,4,6,9,10,14]

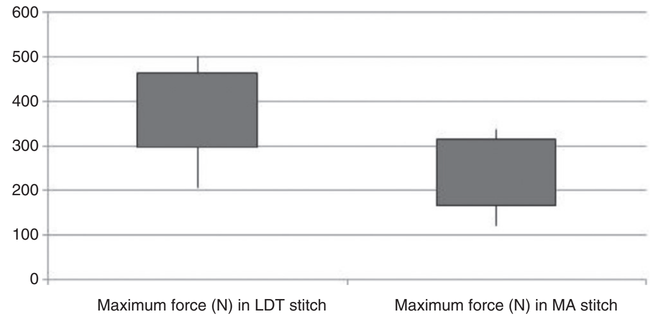

Fig. 6 – Difference in maximum force between the groups.

Consequently, several types of arthroscopic stitches have been described, going from very simple ones to U-shaped stitches, modified Mason-Allen stitches,[4] Mac-Stitch[14] and Lasso-Loop,[8] all with the aim of increasing the resistance of the fixation.

We believe that better healing is directly related to better vascularization of the rotator cuff that is to be repaired, and consequently to less area of ischemia. As shown by anatomical studies, the microvascularization of this structure is oriented parallel to its tendon fibers and progresses from medial to lateral, with a less vascularized area in the region of the tendon of the supraspinatus muscle (Codman's critical area).[15,16] Thus, stitches constructed transversally to the direction of vascularization will result in greater ischemic area and therefore increase the chance of repeated tearing. This does not occur with LDT stitches, because they are parallel and respect the vascularization of the tendon (Fig. 1I).

With the aim of comparing the new stitch that we developed (LDT) with the Mason-Allen stitch modified by Habermeyer, other factors that could alter the results from the samples were excluded, for example failure relating to the tendon–bone interface (poor bone quality, positioning errors, directionality, loosening and even cutting of the suture thread at the openings of the anchors). Thus, with the sheep tendon model, we were able to isolate and individually evaluate each stitch with regard to the force required to produce

Table 1 – Distribution of the variables.

Variable	Stitch	Mean	SD	Minimum	Median	Maximum	*p* value
Age (years)	LDT	1.6	0.211	1.5	1.5	2.0	
	MA	1.5	0.00	1.5	1.5	1.5	
Weight (kg)	LDT	22.46	1.226	20.4	22.3	24.5	0.280
	MA	22.62	1.783	20.3	22.1	25.2	
Width (mm)	LDT	17.65	1.658	14.9	17.8	20.0	0.536
	MA	17.15	1.34	14.20	17.15	19.0	
Thickness (mm)	LDT	3.5	0.638	2.4	3.5	4.4	0.679
	MA	3.78	0.553	2.8	3.7	4.7	
Force to form 5 mm space (N)	LDT	286.6	64.1	183	301	392	0.010
	MA	203.3	80.5	73.5	209.3	315.5	
Force to form 10 mm space (N)	LDT	341.9	87.8	180	345.5	474.3	0.002
	MA	219.7	81.8	68.6	241	300	
Maximum space (N)	MA	246.7	83.6	121.4	287.1	335.9	

SD, standard deviation; Minimum, minimum value; Maximum, maximum value.

displacements of 5 mm and 10 mm and the maximum load needed for the sample to fail.

Unlike Ponce et al.,[17] we did not cut the tendons longitudinally, because their physical conformity was more consistent in the more proximal part of the spine of the scapula, but we obtained a smaller number of samples. We distributed the stitches on our samples and imagined using an anchor. Thus, two LDT stitches were constructed for every MA stitch.

Our results showed that the LDT was superior to the MA stitch, both regarding the force required to form spaces of 5 mm and 10 mm and regarding the maximum traction resistance. This confirmed our hypothesis and makes this stitch an option for suturing in rotator cuff surgery. We observed during the test that the MA stitches resulted in "strangulation" of the tendon, which is bad in relation to its vascularization. This did not occur with the LDT stitches.

In comparing our maximum load results with the results from other biomechanical studies on sheep, we observed that the LDT stitches withstood greater force before sample failure occurred. However, we did not perform cycling of the force applied, as described by Burkhart et al.,[18] which is an important limitation of our study and impedes more trustworthy comparisons.

It is evident that biological factors are fundamentally important in repairing rotator cuff injuries, but these were not an objective of the present study.

Conclusion

We confirmed our hypothesis that LDT stitches are superior to MA stitches from a biomechanical point of view. LDT stitches are an additional option for surgeons when fragile tendons with poor vascularization need to be sutured. They improve the quality of the fixation without increasing the strangulation and consequently the area of ischemia.

Conflicts of interest

The authors declare no conflicts of interest.

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