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Tendon repair with the strengthened modified Kessler, modified Kessler, and Savage suture techniques: a biomechanical comparison

Tendon tamirinde güçlendirilmiş modifiye Kessler, modifiye Kessler ve Savage yöntem - lerinin karşılaştırılması: Biyomekanik çalışma

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Amaç: Bu çalışmada, basit ve uygulaması kolay, ayrıca erken aktif hareket protokollerinin tamir sahasında oluşturduğu güce dayanabilecek bir dikiş tekniğinin geliştirilmesi amaçlandı.

Çalışma planı: Çalışmada, yaşları 12-16 ay arası değişen koyunların tırnaklarına uzanan 30 adet derin fleksör digitorum kasının tendonu kullanıldı. Tendonlar *in situ* tamir edilmek üzere üç gruba ayrıldı. Bir grupta modifiye Kessler tamiri, bir grupta altı dönüşlü (six strand) Savage tekniği, son grupta ise güçlendirilmiş modifiye Kessler tekniği uygulandı. Tüm gruplarda tamir tekniği epitendinöz dikişle birlikte kullanıldı. Biyomekanik testlerde tamir sahasında 3 mm ayrılma oluşumu sırasında uygulanan güç ve kopma olana kadar uygulanan maksimum güç kaydedildi.

Sonuçlar: Modifiye Kessler tamiri kullanılan grupta 3 mm ayrılma ve kopma değerleri sırasıyla ortalama 29.9±2.9 N ve 37.0±4.0 N bulundu. Bu değerler altı dönüşlü Savage tekniği ile sırasıyla 39.1±6.7 N ve 51.3±6.1 N; güçlendirilmiş modifiye Kessler tekniği ile 59.9±8.3 N ve 69.0±8.7 N idi. Güçlendirilmiş modifiye Kessler tekniği kullanılan grupta 3 mm ayrılma ve kopma değerleri diğer iki gruptan anlamlı derecede yüksek; modifiye Kessler tamiri kullanılan grupta her iki değer de anlamlı derecede düşük bulundu ($p<0.001$).

Çıkarımlar: Güçlendirilmiş modifiye Kessler tekniği ile tendon tamiri kopmaya karşı olduğu kadar 3 mm ayrılmaya karşı da en yüksek direnci göstermektedir. Bu biyomekanik özellikler, tamir alanında açılma olmaksızın güvenli bir şekilde aktif harekete izin verebilir.

Anahtar sözcükler: Biyomekanik; kopma; koyun; dikiş teknikleri; tendon/cerrahi; germe kuvveti.

Objectives: The aim of the study was to develop a suture technique that would be simple and easy to perform, but also strong enough to resist the strength formed during early active exercise protocols.

Methods: Thirty flexor digitorum profundus muscle tendons were obtained from lambs aged 12 to 16 months. The tendons were assigned to three *in situ* repair groups, including the modified Kessler technique, six-strand Savage technique, and a strengthened modified Kessler technique, all combined with an epitendinous suture. Each group was subjected to biomechanical tests and the maximum strength of the tendons to rupture and the power exerted to yield a 3-mm separation were recorded.

Results: The mean strengths of the tendons repaired with the modified Kessler technique for 3-mm separation and rupture were 29.9±2.9 N and 37.0±4.0 N, respectively. The corresponding forces were 39.1±6.7 N and 51.3±6.1 N with the six-strand Savage technique, and 59.9±8.3 N and 69.0±8.7 N with the strengthened modified Kessler technique, respectively. Forces to produce a 3-mm separation and rupture were significantly higher with the strengthened modified Kessler repair, whereas the lowest forces were seen with the modified Kessler technique ($p<0.001$).

Conclusion: Tendon repair with the strengthened modified Kessler technique provides the highest resistance to both 3-mm separation and rupture. These biomechanical properties may allow safe and active motion without any gap formation in the repair area.

Key words: Biomechanics; rupture; sheep; suture techniques; tendons/surgery; tensile strength.

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In tendon surgery many repair methods have been developed so as to cope with cohesiveness, gap formation and rupture in repair field. Furthermore, active or passive motion programs are motified to the repaired tendon in order to heal the post-surgeon results.[1,2] However, as much weight is mounted on the repair field during the cyclic active embarkations, early motion protocols, proved to be efficient to avoid post-surgeon tendon cohesiveness, shows the necessity of strong suture techniques. Many researchers stated that the more suture legs passing through the repair field increase the more stretching strength in the repair field increases significantly.[3,4] But these type of suture techniques have difficulties in practice as the complexity increases and so much manipulation is required.[5,6] In addition to this information, although the Modified Kessler suture technique combined with simple epitendinose suture used commonly in tendon surgery is easy and practical to apply, it is stated in various studies that it's not so strong as to permit active movement.[7,8] In our study Strengthened Modified Kessler tendon repair method whose biomechanical qualifications are compared, applied in the clinic for 5 years and successful results were taken.

The purpose of this study is to develop a suture technique that is simple and easy to apply, yet will resist the power occurred by early active movement protocols in the repair field.

Material and method

In this study, 30 pieces of sheep musculus flexor digitorium profundus tendon extended in the sheep aged 12 to 16 months were used (figure 1). The purpose of using these tendons in this study is that besides being easy to obtain, they both have 4-5 mm calibrations, which show a similarity to human hand tendons and easy to apply to test device because of their 10-12 cm lengths. Tendons were taken out from the sheeps' legs obtained from meat integrated companies on the same day and stored in -20 C in plastic bags by wrapping serum physiological (SP) saturated spanches until the day of the study. In the day of the study, after the resolution of tendons in the room temperature is provided, tendons are focused to be kept wet by spanches moistened by SP during the study process. Initially, tendons where attached to wooden plate that will be repaired in both ends by nails. Thus, tendon was cut in the middle sharply as transverse after providing easy repair and manipulation. Afterwards, tendons were divided into 3 groups in order to insutu repair.

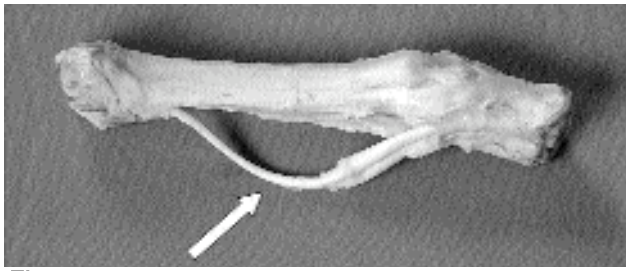

Figure 1. The free and disected view of muscules flexor digitorum longus tendon in the leg.

Group A; Modified Kessler + Epitendinose Suture

Group B; Six Strand (Savage) + Epitendinose Suture

Group C; Strengthened Modified Kessler + Epitendinose Suture

In the figures 2,3 and 4 the schematic view and the applied form of Groups A, B and C can be seen.

In the Strengthened Modified Kessler + Epitendinose Suture, suture is passed as in the classical Modified Kessler technique through one of the cut tendon ends. Afterwards a U stitch is done to the cut from a palmar 1/2 part without spoiling the vas-

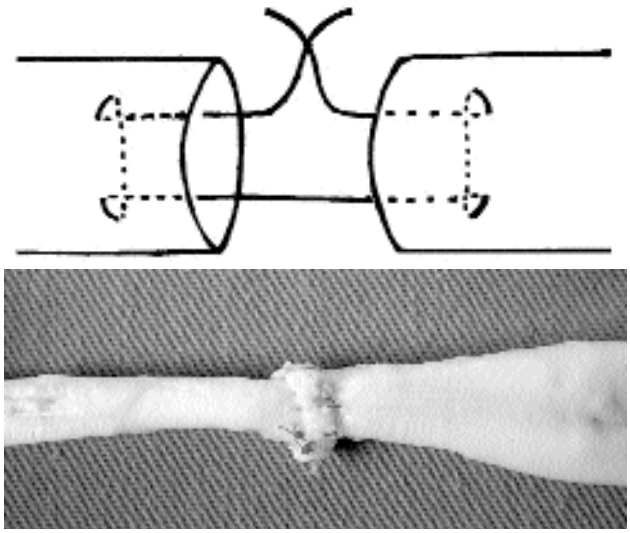

Figure 2. (a) Schematic view of Modified Kessler + epitendinose suture technique and its applied form **(b)** The applied form of Modified Kessler + epitendinose suture technique on tendon

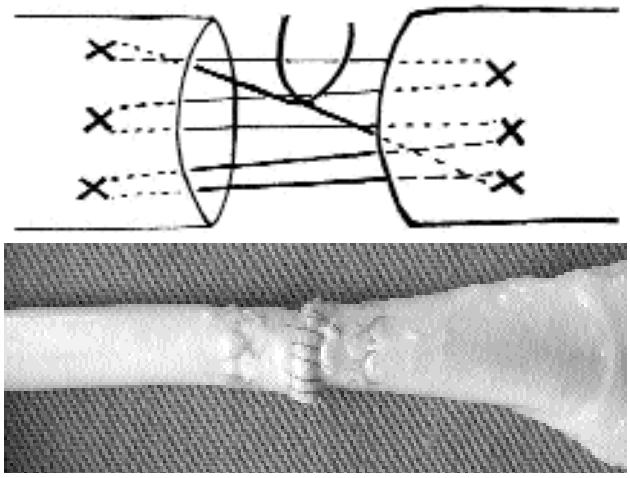

Figure 3. **(a)** Schematic view of Six strand (Savage)+epitendinose suture technique **(b)** Applied form of six strand (Savage) + Epitendinose suture technique on tenton

cularity of tendons from a 2 mm distance to the end of the cuts. The same process is applied to the other tendon leg and knotted. Epitendinose stitches are passed behind the previously applied transvers U stitches and the suture is completed. The purpose of U suture, previously applied to tendon, is to remove the effect of accordionating that may occur during Modified Kessler suture technique and increase the power by avoiding tearing the tendon ends of epitendinose circular stitches. For the center core suture 4/0 tressed polyester suture (ethibond)® and for the epidentinose suture 5/0 propilen monofilaman (prolene)® are preferred. In each group 10 tendons are prepared and tested. The tests were done by a device that can make measurements in international standarts and precision and during the measurement by original handcuffs impermitting the slipping of tendon even in maximum loadings (LLOYD LRX 5K MATERIAL TESTING MACHINE) (figure 5). The machine, whose measurements were done, and the monitor can be monitored in figure 5. Firstly, the sutured tendons will be 3 cm off to the suture line handcuffs and will be 3 cm in the handcuffs and fixed. Afterwards, the possible loosenesses of tendons, being waited for 1 minute in a slight prestretching of 2 Newtons (N), was dispersed and accorded. Later on. constant traction of 10 mm/min was started.

The separation fixation between the ends of the tendons was done by 2.5 grading surgery loop and 3

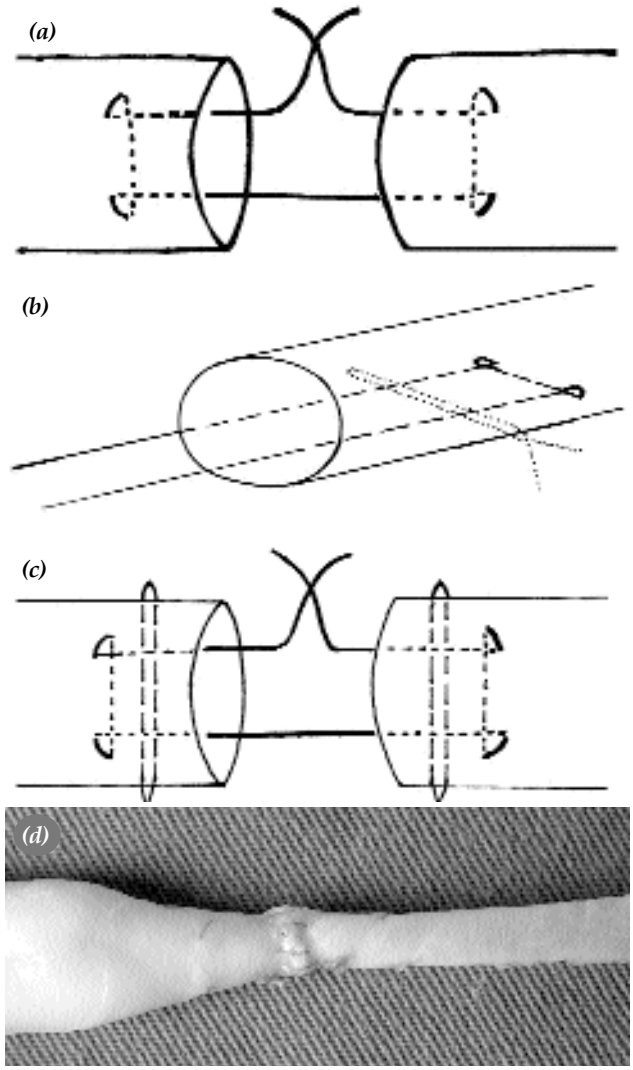

Figure 4. The schematic view of strengthened Modified Kessler + epitendinose suture technique **(a)** The passing of suture through tendon ends according to Modified Kessler technique. **(b)** Placinf of free sutures into tendon ends before knotting the suture ends. **(c)** Completion of Modified Kessler tecnique after knotting the sutures. **(d)** Applied form of strengthened Modified Kessler + epitendinose suture technique on tendon.

mm adjusted electronic compass macroscopically. A small mirror was utilized in order to observe both the front and the back face at the same time. Rupture in the tendon stitches was fixed easily because of both direct observation and the sudden decrease in the power indicator of the device.

The data was presented as average ± SD. As the data was concordant with the normal distribution, in the inter-group comparison, variance analysis

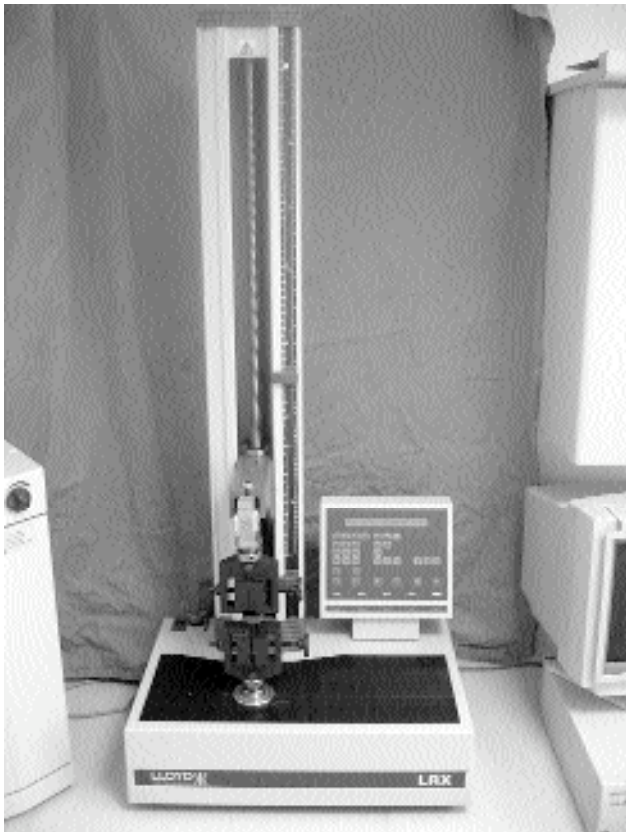

Figure 5. Measurement device used for the tests and the monitor, transferring the obtained values.

(ANOVA) and Post hoc Tukey HSD tests were used. The value of P <0,05 was taken a significance limit.

Results

Group A: Avarage 3mm separation value 29.9 ± 2.9 N, average rupture resistance 37.0 ± 4.0 N

Group B: Avarage 3mm separation value 39.1 ± 6.7 N, average rupture resistance 51.3 ± 6.1N

Group C: Avarage 3mm separation value 59.9 ±8.3 N, average rupture resistance 69.0 ± 8.7 N

3 mm separation rupture resistance in group C increased significantly both in Group A and Group B. The 3 mm seperation and rupture resistance obtained in Group B were significantly higher than that of group A (P< 0.001)

All the data obtained have been shown in Table 1.

Discussion

The purpose of flexor tendon repair is to restore the flexion of fingers. Since it was believed that healing occurred by extrinsic mechanism in the past, the necessity of immobilization for the development of adhesion was advocated.[9] But the narrowness in the finger movement was a frequently encountered result. In the following years, Gelberman and Manske, upon their studies, proved that flexor tendons have the power to heal intrinsically.[10] Furthermore, when it is understood that mobilized tendons healed more quickly and their final pace was stronger than immobilized tendons, some differences have been made in the suture techniques used in the operations and in rehabilitation programs used afterwards.[11] The purpose of the therapy after operation is to protect tendon from cohesiveness by keeping it active. There are two important factors determining the effects of the post-surgery therapy. The first of them is the suture power. The power of the suture must be more than the power that will be applied during the therapy, if it is not the tendon will break off. The other factor is the sliding resistance between the tendon and the pulley systems. The power applied in post-operation therapy must be more than the sliding resistance, otherwise, tendon will wont move and it will stick. These two factors constitute the security borders after tendon surgery.[12]

Flexor tendons, applies a power of 2-4 N during passive flexion without applying resistance a power of, 10 N in flexion that is done against resistance in a slight degree and a power of 17 N flexion against middle degree resistance. During strong grasping this quantity increases up to 70 N.[13-14] It is stated that in order to begin active movement after tendon repairs in a secure way, the initial power of tendon must be 5 times much more than the power that it will compose in flexion against slight resistance. Because the oedema that will develop, the hardness of articulations and sliding resistance developed in repair field obliges these values to be excelled.[15-16] After early active movement concept, another important issue that gained importance is the formation of gap formation. In the during gap formation, the space occurred in between is filled by fibrous tissue and as a result of this a decrease in the tendon power and total articulation movements, hardness and increase in rupture rates have been shown in the study.[12,17,18,19] According to Wade et al. the most important mechanic qualification of tendon suture technique is the resistance against gap forma-

tion that will develop. They have described this stuation as a begining of the seperation without rupture and 3mm lengthened at suture area.[20]

The studies prove that Modified Kessler + epitendinose suture technique used commonly as a repair method in our country and the world, is not efficient. So as to do stronger repairs various studies have been done on different suture techniques (23,24). When literature is reviewed, it is seen that it has close relationship with the suture design of repair power and suture leg number passing the repair field.

The most important quality of Modified Kessler + epitendinose suture technique is that it is easily applied technically and no time is wasted during operation. In this study, average distraction power of 37.0 ± 4.0 N is obtained in the test results of Group A. These values, when the power produced in flexor tendons in slight and middle degrees is taken into account, are not enough to start active movement in the early periods of post-surgery. Also in group A the power of 29.9±2.9 N makes us think that Modified Kessler + epitendinose suture technique is not a suitable technique. So as to solve this problem, many new techniques are defined. But most of them are difficult to apply practically and require much time. But in recent years the Savage technique has been popular because of the fact that it provides biomechanical advantages. In the test results of Group B in which the Savage technique is used, 51.3±6.1 N of distraction power and 39.1±6.7 N of 3 mm separation power were obtained. According to these values, Group B ,when compared with Group A, provides more secure repair possibility to begin early active movement. But, besides the advantage it provides, it has disadvantages in that it is difficult to apply and it requires much more time when compared to Modified Kessler technique. Because of these disadvantages, we aimed at developing a technique that is easy to apply, strong and dependable. In the test results of the method we developed, we had 69.0±8.7 N distraction power and 59.9±8.3 N 3 mm separation power. As it can be understood from the results that Modified Kessler + Epitendinose Suture technique becomes more efficient than Six Strand (Savage) + epitendinose suture technique. Another biomechanical quality that draws attention, besides the high resistance against rupture, is resistance against 3 mm separation. Thus it can provide a possibility of an active movement in a secure way without gap formation. However, Hoang et al. published 3 mm gap formations named as ocilator, residual, and catastrophic after tendon repairs. If we consider the post-surgery rehabilitation programs as cyclic engagements, we think that measurement that will be done in the future by cyclic engagements in tendon biomechanical studies will give more secure results.

Furthermore, in addition to easy application and biomechanical advantages the Strengthened Modified Kessler + epitendinose Suture technique avoids the roughness in the repair field of Modified Kessler + Epitendinose Suture technique and thus provides more slippery and smooth repair field. We think that no accordionation will be in tendon ends and thus it will show less sliding resistance.

We think that the results of the invitro test study are prospective in the repair of flexor tendon injuries. However, this study constitutes the first step of Strengthened Modified Kessler + epitendinose repair method. In this study, tendon feeding of additional sutures and the effects of recovery process are not studied. It shows the necessity of evaluation of invivo studies before going through a clinical application. Further invivo studies that will be done in this direction, will highly contribute to the repair of flexor tendon injuries which is a serious health problem despite all the various technological developments.

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