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Single side locking on the opposite of the modified Kessler tendon repair prevents gap formation and suture pull-out: a biomechanical evaluation in sheep tendons

Modifiye kessler tendon onarımında karşı yanda uygulanan tekli kilitleme yöntemi ile ayrışma ve dikiş kopmasının önlenmesi: Koyun tendonları üzerinde biyomekanik inceleme

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Objectives: Locking loops are invented to prevent pull-out complication during early active rehabilitation after flexor tendon repair. This study compares the mechanical properties of the side-locking modified Kessler repairs with four- and two- side locking points.

Materials and methods: Twenty fresh flexor digitorum profundus tendons of the healthy adult sheep forelimbs were sutured by the two-strand modified Kessler with the side-locking loop technique (group A: four locking points), and by the two-strand modified Kessler repair method with a side locking knot on the opposite corners of the repair (group B: two locking points). To assess the mechanical performance of the repairs, the tendons were subjected to a linear non-cyclic load-to-failure test using a material testing machine. Outcome measures included the 2.0 mm gap force at the tendon ends, the ultimate forces and the mode of failure.

Results: The mean value for the 2.0 mm gap strength was 19.2±1.4 for group A and 19.3±1.9 for group B. The mean value of the failure strength was 33.1±2.6 for group A and 29.8±3.2 for group B. Regarding the 2.0 mm gap strength between the tendon ends, no significant difference was observed between the two groups. There were statistically significant differences in failure strengths of the two groups (p=0.019). As regards the mode of failure, no suture pull-out was observed. All the specimens failed due to suture breakage at the repair site.

Conclusion: Results of this study revealed that gap formation and suture pull-out can be prevented using single side locking points on the opposite corners of the modified Kessler repair.

Key words: Flexor tendon repair; side locking points; biomechanic evaluation.

Amaç: Bu çalışmada, fleksör tendon onarımlarından sonra erken rehabilitasyonda dikiş kopması komplikasyonunun önlenmesi için geliştirilen yandan kilitli modifiye Kessler fleksör tendon onarımı yöntemi ile iki ve dört köşeden kilitli yöntemin mekanik özellikleri karşılaştırıldı.

Gereç ve yöntemler: Sağlıklı yetişkin koyunlardan elde edilen 20 adet taze ön ayak fleksör digitorium profundus tendonu iki gruba ayrılarak yandan kilitli modifiye Kessler yöntemiyle onarıldı. Birinci grupta (A grubu) dört köşeden yan kilitleme yöntemi uygulandı. İkinci grupta (B grubu) ise, dört köşeden sadece karşılıklı iki çapraz köşeye yan kilit düğümü uygulanırken, diğer iki çapraz köşeye kilitsiz düğüm uygulandı. Onarımın mekanik özellikleri, mekanik test cihazı ile tendon kopana kadar, sürekli tek yönlü yük uygulanarak ölçüldü. Tendon uçları arasında 2.0 mm ayrışma gücü (N), kopma gücü (N) ve kopma şekli değerlendirildi.

Bulgular: 2.0 mm ayrışma gücü karşılaştırıldığında; ortalama değer A grubunda 19.2±1.4, B grubunda 19.3±1.9 olarak bulundu. Ortalama kopma gücü ise A grubunda 33.1±2.6, B grubunda 29.8±3.2 bulundu. Tendon uçları arasında 2.0 mm ayrışma gücü değerlendirildiğinde; iki grup arasında anlamlı fark saptanmadı. Kopma gücü karşılaştırıldığında ise iki grup arasında anlamlı fark bulundu (p=0.019). Her iki grupta da hiçbir örnekte dikiş kaymasına bağlı yetmezliğe rastlanmadı. Her iki grupta da kopma yeri iki ucun arasında kalan düğümün altından gerçekleşti.

Sonuç: Bu çalışmanın sonuçları, çapraz köşelere uygulanan iki adet yan kilit düğümü tekniğinin, onarım bölgesindeki ayrışmayı ve dikiş kaymasına bağlı yetmezliği önlediğini göstermiştir.

Anahtar sözcükler: Fleksör tendon onarımı; yan kilit düğümü; biyomekanik değerlendirme.

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The type of core suture loop configuration is essential to improve the flexor tendon repair strength.[1-5] A grasping loop may pull through the tendon fibers when excessive tension is applied.[6] Locking loops have been introduced to prevent this complication and to increase the tensile strength of the flexor tendon repair. In addition, increasing the number of suture strands across the repair site for reinforcement is considered effective.[7-9] The location of the core suture knot is also considered important in influencing the tensile strength of the repair. Hatanaka et al.[10] modified the locking Kessler suture repair technique and Yotsumoto et al.[11] devised the side-locking loop technique in which the locking loops are located on the side of the tendon.

A biomechanical tensile strength study comparing two and four side locking points in modified Kessler tendon repair was not performed until now. We assumed that only two locking points across the repair site will biomechanically be sufficient to enhance the single modified Kessler repair in tension.

The purpose of the current study is to show whether the number of the locking points affect the strength of the repair and the failure pattern. We investigated the effect of decreasing the locking points in the modified locking Kessler method by observing the resistance to repair site gap formation, failure strength and mode of failure, using sheep flexor tendons.

MATERIALS AND METHODS

In this study, 20 fresh sheep forelimbs were dissected to obtain the flexor digitorum profundus tendons. The sheep (average age 8-12 months) were all healthy adults and had been sacrificed for commercial purposes. Obtained tendons' circumference was approximately 4-5 mm and the mean length was 10-12 cm. Tendons were removed from fresh limbs and kept moist in saline solution until testing. The specimens were randomly placed into two equal groups. Initially, the tendons were attached to wooden plates at their both ends by pins. A transverse sharp incision was made in the mid portion of each tendon and then the repair was performed.

In group A, a two-strand modified Kessler suture in locking configuration, using side locking loops (four locking points; Figure 1), was used to repair the incision.[11]

In group B, a two-strand modified Kessler suture with two side locking points and two grasping points on the opposite corners of the repair was used (Figure 2).

All tendons were repaired using a 4/0 polypropylene monofilament core suture (Prolene®, Dogsan, İstanbul). Immediately after the repair, the tendons were vertically placed into the non-slipping jaws of soft tissue clamps and mounted to a material testing machine (model TIRA test 24500; Demgen, Werkzeugbau, GmbH). All tendons were subsequently loaded to failure at a cross-head speed of 20 mm/minute and the force versus displacement data was recorded. The force producing 2.0 mm gap as detected visually with the aid of operating loupes[12] and maximum force prior to rupture (ultimate force) were determined.

Data are presented as mean ± standard deviation. Statistical analyses of the data were performed using two-way ANOVA followed by Tukey (HSD) post-hoc test.

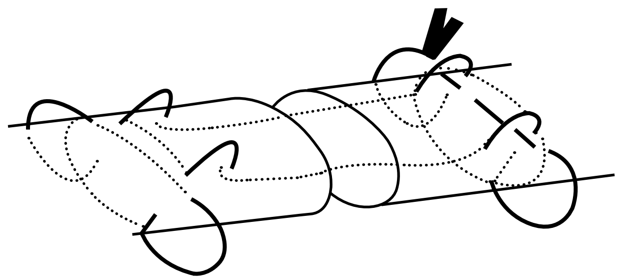

Figure 1. Side locking loop technique as described by Yotsumoto et al.[11] The original technique includes four side-locking points.

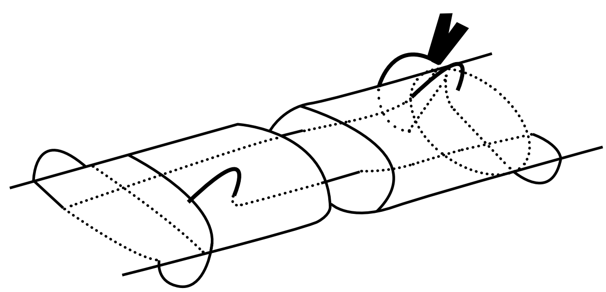

Figure 2. The modified side locking loop technique suggested by the author. The repair includes two side locking points on the opposite corners of the repair. The other two points are grasping points used commonly in the modified Kessler repair.

TABLE I

Mechanical properties of flexor tendon repairs performed using modified Kessler repair with four side locking points (group A) and modified Kessler repair with two locking points (group B). Data are presented as mean (SD)

Group	Number of samples	Suture technique	2.0 mm separation-gap strength (N)	Breaking strength (N)
A	10	Modified Kessler repair with four locking points	19.2±1.4	33.1±2.6
B	10	Modified Kessler repair with two locking points	19.3±1.9	29.8±3.2

SD: Standard deviation.

RESULTS

Despite differences in the number of the locking points, the results of the test showed no difference in the failure pattern between the two groups. The mean values of the gap strength was close (group A=19.2±1.4 N, group B=19.3±1.9 N) in both groups. There were no statistically significant differences in gap strengths of the two groups ($p=0.816$; Table I).

The mean value of the failure strength was 33.1±2.6 for group A and 29.8±3.2 for group B. There were statistically significant differences ($p=0.019$) in failure strengths between the two groups. Regarding the mode of failure, no suture pull-out was observed and all the specimens failed due to suture breakage at the repair site.

DISCUSSION

In this study, we found that the modified Kessler repairs with two side locking points and repairs with four side locking points had similar resistance to gap strength, whilst the failure strength of the repair with four locking points were higher than that of the two locking point group. In addition, when performing the modified Kessler repair, we found that the pull-out complication can be prevented, by using only two side locking points instead of four locking points.

Previous studies have researched the effect of various locking configurations on the pull-out of the sutures and the strength of the repair.[1,4,6,10,11,13,14] In our study, we researched the effects of decreasing the number of the locking points on the pull-out of the sutures and the strength of the repair.

It has been proven that a locking loop provides increased tensile strength of repair, as compared with the grasping loop which may pull through the tendon fibers when excessive tension is applied.[6]

Yotsumoto et al.[11] investigated the factors that influence tensile strength and resistance to gap formation at the repair site of the tendon suture (stiffness) by comparing the location of the locking loops and the location of the knot. They suggested that a greater tensile strength with less of a gap is obtained by forming locking loops in the side portion of the tendon and forming knots far from the tendon stump.

Our study shows that a single side locking point on the opposite corners of the repair is sufficient to convert a grasping modified Kessler repair to a locking repair and can prevent the pull through the tendon fiber. However, it was found that more side locking points can cause statistically significant increases in the failure strength of the repair.

Xie and Tang[13] have compared the circle lock and the cross-lock configurations and they found that the circle-lock repairs without cross locking component produce tensile strengths similar to cross locking repairs used by many surgeons. In addition, they found that the locking configuration has no effect on the strength of the repair. In the same study, they also found that the gap resistance and the ultimate strength are not dependent on the location of the single cross-lock in relation to the tendon surface. Compared to the study performed by Xie and Tang,[13] in which they used similar numbers of locking points, we used the modified Kessler repair so that we can determine the effect of changing the number of the locking points.

The cross-sectional area encompassed by the locking loop, which has been shown to affect the biomechanical properties of the repair, was standardized to 30% (15% per loop) of the whole cross-sectional area of the tendon.[11,14]

Involving 30% of the whole cross sectional area of an injured tendon within the locking points may compromise the minute vessels inside the tendon. We believe that we can minimize the vascular compromise by minimizing the cross sectional area involved within the locking points by using single locking points on the opposite corners of the repair.

In vivo measurement of the force in an uninjured flexor tendon has shown that an active finger motion generates more tension in the flexor tendons than the passive motion of the tendons. The passive motion of the fingers generates 1 to 9 N, whereas an active motion generates 1 to 29 N (mean 19 N), and a safe repair should withstand these forces.[15]

The respective mean values of the gap strength after loading measured 19.2±1.4 N and 19.3±1.9 N with the two-strand (four point) side-locking loop technique and the two-strand (two point) side-locking loop technique repair methods, respectively.

In our clinic, the rehabilitation of flexor tendon injuries vary according to the patient's compliance with the rehabilitation program. For patients with poor compliance, we prefer to use controlled passive finger motion programs in the first three weeks after the repair.

Since the values obtained with the two methods are higher than the published biological loads during the passive motion; in vivo, these suture techniques would be unlikely to cause suture ruptures through mild movements during the three-weeks long postoperative passive range of motion rehabilitation. This approach may facilitate safe rehabilitation after surgery for patients with poor compliance with the active flexor tendon rehabilitation programs.

Whilst this is an experimental study on sheep flexor tendons which may differ in structural quality from those of the human; they are readily available, less costly and used in a previous biomechanical studies.[16] We used a non-cyclical load and the effect of tissue healing was not taken into consideration. Furthermore, these laboratory tests should be supported by in vivo experiments to evaluate the effects of these changes and modifications on the healing properties.

In the commonly used modified Kessler repair with the side locking technique, a single side locking point on each side of the repair can prevent pull-outs successfully. Minimizing the number of the side-locking points has no effect on the gap strength but it affects the failure strength of the repair.

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