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EFFECT OF CYCLIC LOADING ON THE STRENGTH OF FLEXOR TENDON REPAIR IN VITRO STUDY

By

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ABSTRACT

Background: The initial strength of the repair depends on the material properties and knot security of the sutures as well as on the holding capacity of the suture grip of the tendon.

Objective: Detecting the effect of cyclic loading on the strength of flexor tendon repair using 6 strand Tang suture experimentally.

Materials and Methods: In the present ex vivo study of 50 sheep flexor tendons, six strand Tang suture technique was used: Twenty five repairs were subjected to cyclic tensile testing, and twenty five repairs were subjected to static tensile testing using 4/0 polypropylene simple suture material + epitendinous continuous running sutures using 5/0 polypropylene suture material.

Results: The results of the study showed that 44 % survival at 41.7 N cyclic testing, without evidence of significant gap formation or rupture and the breaking force on continuous loading mean 55.95 N. The Tang suture method provided much more sufficient gap resistance and tensile strength able to withstand early active mobilization after primary flexor tendon repair.

Conclusion: The Tang suture method provided sufficient gap resistance and tensile strength able to withstand early active mobilization after primary flexor tendon repair. There were some disadvantages regarding to time consuming during surgery and difficult to use in pediatrics and small tendons.

Keywords: Flexor tendon repair, six strand Tang suture, yields force.

INTRODUCTION

Numbers of factors affect the functional biomechanics of flexor tendon repair, 1st factor is intact pulley system which prevent bowstring of the flexor tendon, 2nd factor is synovial fluid for nutrition to The tendon, lubrication and permitting frictionless gliding between the tendons, 3rd factor supple joints to permit motion &if stiffness occur affect tendon function, Finally tendon excursion which is important factor for tendon function biomechanics *(Manske, 2005)*.

In case of tendon injury you should assess &make good evaluation of injury to trying to regain this functional biomechanics of the tendon, so initial strength of repair depend on 2 factor, 1st material properties (suture caliber & material itself),2nd knot security of the suturing *(McDowell et al., 2002)*. The case improved by increase numbers of strands crossing the repair site *(Barrie et* *al., 2001).* Finally the holding capacity of the repair of the tendon depend on configuration *(Taras et al., 2001),* size *(Xie and Tang, 2005)* & number of grips *(Xie et al., 2005).*

Physiotherapy after operation is very important step with main purpose which is the protection of the tendon from adhesion by keeping it active. Depending on 3 factors, 1st power of suture should be more than the power that applied during the therapy 2nd suture power, if not respect this two factor the tendon will be break off. 3rd factor is the sliding resistance between the tendon and the pulley system it should be more than the sliding resistance *(Kubota et al., 1996).*

The aim of this study was to know the cyclic loading effect on the strength of flexor tendon repair using 6 strand Tang suture experimentally.

PATIENTS AND METHODS

Our study was well prepared at Department of Orthopedic Surgery, Faculty of Medicine, Al Azhar University.

The sheep are all healthy, and they had been killed for commercial purposes at a slaughterhouse. Flexor tendons are of the same diameter as that of flexor tendons in humans. All repairs performed by the same surgeon. The properties of porcine FDP-II tendons have been shown to be comparable with human flexor tendons.

The tendons were tested for tensile strength in the Textile Metrology Lab., National Institute for Standards (TML-NIS) Cairo, Egypt. A total of 50 sheep forelimbs tendons of the same caliper were cut and sutured using Tang 6 strand repair technique using 4/0 polypropylene for core suture + epitendinous continuous running sutures using 5/0 polypropylene.

A looped locking line is first anchored on the dorsolateral aspect of the distal tendon stump. The lines are then inserted into the proximal tendon and passed longitudinally back towards the proximal tendon stump. A knot is tied over the tendon surface. Another two looped lines are inserted from the contralateral dorsolateral aspect the tendon and from the ventral aspect of the tendon.

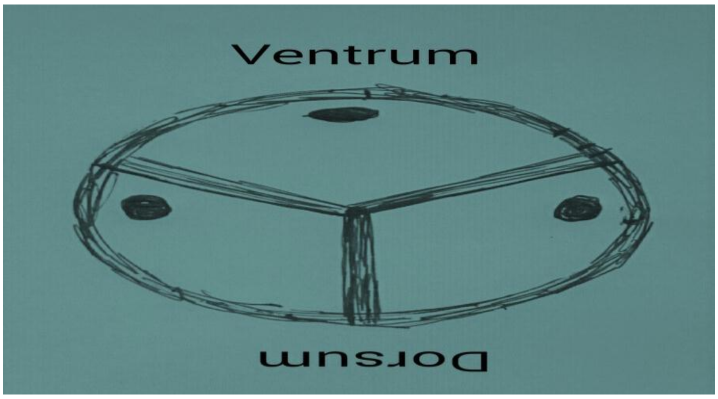

Figure (1): A looped locking line is first anchored on the dorsolateral aspect of the distal tendon stump.

The suture configurations, locations of the longitudinal strands, and number of knots in the Tang method of tendon repair. In tendon cross-sections, three suture groups are placed at points of a triangle to avoid interference to the dorsal center of the tendon where the vascular networks converge. The dorsolateral sutures may act as tension bands to resist gapping of the tendon **(Fig 2)**.

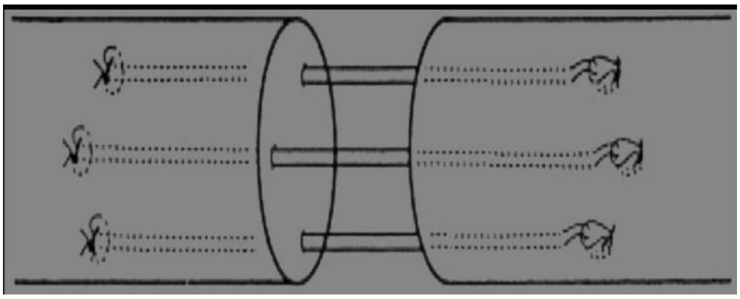

Figure (2): Tang 6 strand repair technique (Wang et al., 2003).

Tang 6 strand repair technique done by using simple sutures the same manner as looped sutures but different in strands arrangement inside cut sections (Figures 3, 4, 5).

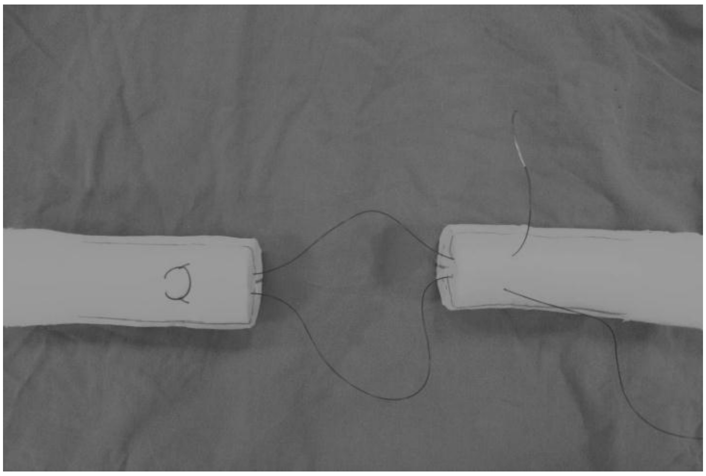

Figure (3): Tang 6 strand repair technique done by using simple sutures.

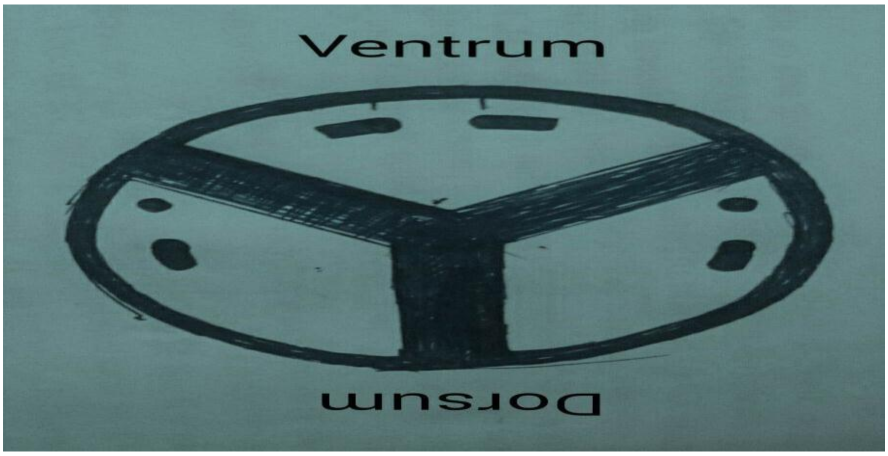

Figure (4): Cut section of Tang 6 strand repair technique using looped sutures.

Figure (5): Cut section of Tang 6 strand repair technique using simple sutures.

Tang 6 strand repair technique done by using simple not looped sutures (Figure 6).

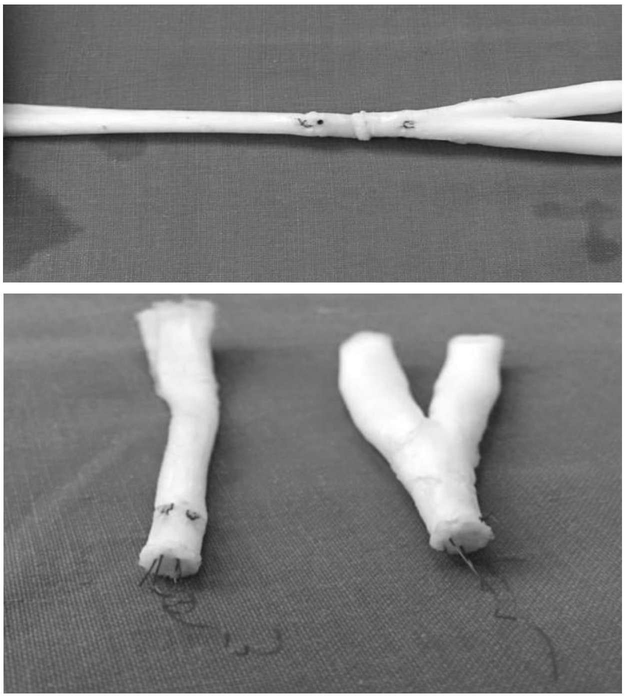

Figure (6): Six strand tang repair

The tests were performed using a tensile strength measuring machine **(Zwick, 2010)**.

The measurements were displayed on a monitor screen, they are expressed in Newton. The length of the tendon segment between the two clamps of the testing machine was 55 mm and the loading speed was 0.2 Hz. The specimen then divided to two groups each one contain 25 tendons:

Group (A) Cyclic loading: A staircase protocol was employed. All tendons were initially loaded to a maximum load of 31.7 N for 500 cycles. Loading was subsequently increased by 5 N for an additional 500 cycles for surviving repairs. This procedure was repeated until failure occurred at a gap of more than 2 mm.

Group (B) Continuous loading: Twenty five samples were exposed to direct continuous loading until failure occurred.

RESULTS

In cyclic loading the tendon repairs displayed a gradually increasing gap between the tendon ends. Maximum gap formation measured for The survival tendon repairs was 1.8mm (Failure occurred at a gap of more than 2 mm). The Tang technique demonstrated 80 % survival at 31.7 N testing, 72 % survival at 36.7 N testing and 44 % survival at 41.7 N testing without evidence of significant gap formation or rupture, **Table (1)**.

Table (1): The survivals % of stair case cyclic loading protocol sing Tang technique

Cyclic loading	500 C	1000 C	1500 C
Percentage	20	18	11
	80%	72%	44%

In continuous loading The mean breaking force of the six strand Tang repairs exposed to direct continuous loading until failure in tension using 4/0 polypropylene suture material was 55.95±2.19 N, **Table (2)**.

Table (2): Descriptive statistics for breaking force

Breaking force			
Mean	**SD**	**Minimum**	**Maximum**
55.95	2. 19	41.11	77.7

DISCUSSION

Many core suture techniques for flexor tendon repairs have been advocated, the most common of which is, the modified Kessler, the Bunnell, the Kessler the Savage, and the Pulvertaft *(Hatanaka and Manske, 2000).*

Tang technique increase the strength of the repair due to more suture legs passing through the repair field in order to provide safe early active motion which prevent the post-operative adhesion (the main cause of limited range of motion). However, with some disadvantages as technically demanding in clinical settings requiring multiple subsequent needle passes that increase tendon handling, longer time than other techniques.

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 (25N), because of the postoperative edema that will develop, the hardness of articulations and the sliding resistance which has developed in repair field *(Linnanmaki et al., 2016).*

The strength of the repair was evaluated experimentally on animal tendons using a tensile strength measuring machine.

Unlike other studies, the staircase technique employed assesses each repair for a range of load levels, thus minimizing concerns regarding selection of a suitable magnitude for a single applied load.

Cyclic testing protocol was defined as a procedure that subjected a group of repaired flexor tendons to repetitive loading. Preload (5N) was the force before repetitive loading started. This was also the minimum force the repaired tendon was subjected to during cyclic loading. We believe that the most convincing reason for the use of pre-load is to simulate resting tension of the tendons after repair. This has been reported as 1 N for a healthy intact FDS tendon in vivo *(Matheson et al., 2005).* Cyclic load (31.7/36.7/41.7N) was the maximum force that the repaired tendon is subjected to during cyclic loading. Normally, the Flexor tendons, apply a power of 2-4 N during passive flexion without applying resistance, a power of 10 N in flexion that is done against a slight degree resistance and a power of 17 N in flexion against middle degree resistance. During strong grasping this power increases up to70 N *(Latendresse et al., 2005).* Number of cycles (500/1000/1500cycle) was the number of repetitions during the protocol that the repaired tendon was dynamically loaded. Some studies chose the number of cycles based on previous findings that 90% of measured gap for core-only repairs was reached by 200 cycles, while 500 cycles were sufficient for composite repairs *(Aoki et al., 1994, Piskin et al., 2007* and *Al-Qattan & Al-Turaiki, 2009).* Frequency (0.2Hz) was the number of cycles over time. Frequency should be based on the rate of the performed exercises. Based on a rehabilitation protocol that conducts flexion and extensions of five to six times per minute, the frequency were set to a rate of 0.1 Hz *(Sanders et al., 1997).*

Matheson use a similar protocol involving 10 flexion and extensions per minute yielding a frequency of 0.2 Hz *(Al-Qattan and Al-Turaiki, 2009).*

Aoki et al. (1994) described the results of cyclic testing at 10 N of, Becker, and Savage techniques, the Kessler as well as a new technique incorporating a Dacron splint of varying sizes. Three of 7 Kessler-repair tendons and 1 of 6 Becker-repair tendons ruptured, in comparison with no ruptures for the other techniques. No Savage repair or splinted repair ruptured or gapped more than 2 mm after 40,000 cycles, suggesting these techniques are more resistant to cyclic loading *(Aoki et al., 1994).*

Other study showed that the Silfverski-old-, Halsted-, and Tajima-repair tendons fail frequently in cyclic testing at loads representative of active digital motion. The Savage technique able to withstand loads of 35 N without gap formation or rupture.

Cyclic loading testing is better than static linear testing in postoperative clinical loading of the tendon repair *(Pruitt et al., 1994).*

Also, offers important advantages over static testing. Pruitt et al. have shown that cyclic testing demonstrates gap formation at lower loads than does static load-to-failure testing. Because it is more physiologic, cyclic testing may provide more relevant information regarding the failure characteristics of a tendon repair *(Pruitt et al., 1994).*

The mean breaking force of the six strand Tang suture repair technique was 55.95±2.19N.

Al-Qattan and Al-Turaiki in (2009) harvested fresh flexor profundus tendons from the hind feet of adult sheep and examined their tensile strength in three types of repair the modified Kessler technique (a two-strand repair), two 'figure of eight' sutures (a four-strand repair) and three 'figure of eight' sutures (a six-strand repair) using polypropylene suture material. The mean breaking forces for the double strand technique was 48.0 N, and for the six strands repair was 93.3 N.

Piskin et al. (2007) compared different suture techniques in a biomechanical study of lamb's tendons using polyester suture material for the core suture and polypropylene suture material for the peripheral suture. The mean strengths of the tendons repaired with the modified Kessler technique for rupture was 37.0±4.0 N. The corresponding force was 51.3±6.1 N with the six-strand Savage technique.

Mobilized tendons healed more quickly and stronger than immobilized tendons and that early active mobilization enhances tendon healing *(Gelberman and Manske, 1985).* Early motion in the postoperative period took place. The desire for maximal mobilization is obviously restricted by increased risk of rupture. This nessicates the presence of a strong repair that permits early motion *(Pruitt et al., 1991).*

CONCLUSION

The Tang suture method provides sufficient gap resistance and tensile strength able to withstand early active mobilization after primary flexor tendon repair. But the Tang method has some disadvantages because it takes longer time and long learning curve and difficult to use in small tendons.

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دراسه تجريبية لبيان مدي تأثير التحميل الدوري علي قوة إصلاح قطع الأوتار القابضة لليد

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خلفيــة البحــث: إن الحركــة النشــطة المبكــرة للأصــابع المصــابة بعــد إجــراء جراحــة إصــلاح الــوتر تســرع الإلتــام وتقلــل الإلتصــاقات ولكــن ذلــك مقيــد بزيــادة إحتماليــة إعــادة قطــع الــوتر الــذى تــم اصــلاحه ممــا يســتلزم عمــل طريقــة إصــلاح قويــة تســمح بهــذه الحركة النشطة المبكرة.

الهــدف مــن البحــث: معرفــة تــأثير التحميــل الــدوري علــى قــوة إصــلاح وتــر الإنقبــاض بإستخدام خياطة تانج ذات الست خيوط بشكل تجريبي.

مــواد وطــرق البحــث: إحتــوت هــذه الدراســة التجريبيــه علــى خمســين عينــه مــن الأوتــار تــم تشــريحها مــن أرجــل المــاعز تــم قطعهــم ثــم اصــلاحهم بطريقــة تــانج باســتخدام خــيط البــولى بــرولين 0/4 و خــيط 0/5 بــولي بــرولين للغــرزة الطرفيــة. مقســمه إلــي مجمــوعتين احتــوت كــل واحــده علــى خمســه و عشــرين عينــة مــن الأوتــار. وتمــت اختبــار المجمــوعتين باســتخدام جهــاز قيــاس قــوة الشــد (Zwick/Z010) المجموعــة (أ) تــم اســتخدام بروتوكــول تحميــل دوري الــدرج. تــم تحميــل جميــع الأوتــار مبــدئيًا بحمولــة أقصــاها 31.7 نيــوتن لمــدة 500 دورة. تــم زيــادة التحميــل بعــد ذلــك بمقــدار 5 نيــوتن لمــدة 500 دورة إضــافية للإصــلاحات المتبقيــة. تــم تكــرار هــذا الإجــراء حتــى حــدث الفشــل (فشــل أكثــر مــن 2 مــم). المجموعــة (ب) و تــم إختبارهــا بواســطه التحميــل المستمر

نتــائج البحــث: المجموعــة (أ) أظهــرت تقنيــة تــانغ بقــاء 80 ٪ مــن العينــات فــي اختبــار 31.7 نيــوتن و 72 ٪ فــي اختبــار 36.7 نيــوتن و 44 ٪ فــي اختبــار 41.7نيــوتن دون دليــل علــى وجــود فجــوة كبيــرة أو تمــزق. المجموعــة (ب) كــان متوســط قــوة قطــع الــوتر 55.95 نيــوتن طريقــة تــانج طريقــة قويــة وآمنــة ممــا تســمح بحركــة نشــطة ومبكــرة مابعد الاصلاح مع مود حركى افضل وقدر افضل على تنى الاصابع ضد مقاومة.

الخلاصة: توفر طريقة خياطة تانغ مقاومة كافية للفجوة وقوة الشد قادرة على تحمل التعبئة النشطة المبكرة بعد إصلاح وتر العضلة المرنة. ولكن مع بعض العيوب المتعلقة باستهلاك الوقت أثناء الجراحة وصعوبة استخدامها في طب الأطفال والأوتار الصغيرة.