BIOMECHANICAL EVALUATION OF FOUR STRAND FLEXOR TENDON REPAIR TECHNIQUES, USING A DOUBLE FIGURE OF 8 TECHNIQUE

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ABSTRAK

Pengenalan: Bertujuan untuk melaksanakan penilaian biomekanikal untuk menentukan kekuatan, ketegangan muktamad dan punca kegagalan dua kaedah pembaikan tendon yang terkenal, iaitu kaedah ‘Modified Kessler’ dan Kaedah ‘Cruciate’ berbanding kaedah ‘figure of eight’ yang tidak banyak digunakan.

Metodologi: Dua puluh empat tendon Achilles daripada dua belas ekor ayam dewasa telah diagihkan secara rawak kepada tiga kumpulan dengan mengunakan kaedah ‘Four Strand Modified Kessler’, kaedah ‘Four strand cruciate’, dan kaedah ‘Four strand double figure of eight’. Dua puluh empat tendon Achilles daripada dua belas ekor ayam dewasa diperolehi, dan sekali lagi diagihakan secara rawak kepada tiga kumpulan yang sama, tetapi kali ini dengan pembaikian tambahan yang ber-epitendinous. Kesemua pembaikan tendon dilakukan dengan mengunakan jahitan monofilament polypropylene yang bersintetik dan serap sendiri

Keputusan: Kaedah ‘Four Strand double figure of eight’, mempunyai kekuatan dan ketegangan muktamad yang tertinggi, ini diikuti oleh kaedah ‘Four strand modified Kessler’ dan kaedah ‘Four Strand Cruciate’. Tendon yang diperkuatkan dengan jahitan tambahan ber-epitendinous memberi keputusan yang lebih baik dan positif

kesimpulan: Daripada kajian biomekanikal ini, teknik ‘Four Strand double figure of eight’ merupakan kaedah yang disyorkan berbanding kaedah lain. Ini adalah kerana selain kekuatannya yang terbukti, kaedah ini tidak rumit, lebih mudah dan menjimatkan masa. Kepentingan dan kekuatan tambahan yand diperolehi daripada jahitan tambahan epitendinous jelas terlihat. Ini merupakan satu teknik yang mampu berjaya dari segi klinikal dan boleh diterima untuk digunakan dalam rawatan kecederaan tendon flexor pada tangan manusia

Kata kunci: *flexor tendon, pembaikan, biomekanik, jahitan monofilament polypropylene*

ABSTRACT

Introduction: To determine and biomechanically evaluate the tensile strength, stiffness and mode of failure, of two well established tendon repair techniques, which are the modified Kessler and cruciate technique with the lesser known figure of 8 technique

Methodology: Twenty four Achilles tendon of adult chickens were randomized into three groups which were a modified four strand Modified Kessler technique, a four strand cruciate technique, and a double figure of eight technique in order to obtain a four strand core suture. An additional twenty four Achilles tendons of adult chickens were obtained and randomized into the same three groups but with an additional running epitendinous repair. All repairs were performed using a synthetic, non-absorbable, monofilament polypropylene suture material

Results: The double figure of eight technique had the highest mean ultimate tensile strength, followed by the modified four strand Modified Kessler technique and the four strand cruciate technique. Analyzing the test with an epitendinous suture significantly affected the results positively.

Conclusion: The double figure of eight, four strand suture technique was the strongest and relatively less technically demanding technique to perform in this study. The importance and additional strength provided by epitendinous suture was evident. This may be a clinically acceptable technique to perform in flexor tendon injuries of hand in humans.

Keywords: *flexor tendon, repair, biomechanics, monofilament polypropylene suture*

Chapter 1

INTRODUCTION

1.1 INTRODUCTION

Injuries to the Flexor tendon of the hand are not uncommon. In the early 20^{th} century, surgical outcome in the field of primary flexor tendon repair was considered a disaster. Any injury of the flexor tendon of the hand at the level of zone two had a poor outcome, hence the term ‘no man’s land’ was coined.

Primary repair of a lacerated tendon was deemed unfavourable, as adhesion formation over the surgically repaired site resulted in a total loss of movement of the affected digit. Primary repair was considered an incompetent form of management. This led to an endorsement towards delayed reconstruction using an autograft.

However, towards the last quarter of the 20^{th} century, there was a change in direction back towards primary repair, as after a period of restriction in movement of up to three weeks post repair, function was regained after initiation of passive range of movement exercises. Primary repair of a lacerated tendon had since become, and still remains the method of choice of treatment.

Ever since then, there has been major strides in the comprehension of treatment of intra-synovial flexor tendon repair and its rehabilitation. It was only after the demonstration and establishment of repairing flexor tendons primarily within its tendon sheath, along with a structured rehabilitation programme, the concept of intrinsic vs extrinsic healing mechanisms was introduced.

This concept of tendon healing without the formation of fibrous adhesions has been both experimentally and clinically proven in numerous studies throughout the years. Currently, research has been more focused in improving the outcome of flexor tendon repair based on its strength, the efficacy of its gliding surface, and early initiation of rehabilitation.

The objectives of a surgical repair for flexor tendon injuries are specific; obtain a repair strength which is significant enough to permit a postoperative mobilization protocol that will prevent the formation adhesions, encourage the remodelling of its gliding surface, and eventually make healing of the repair site an uneventful possibility.

Therefore, the strength of a repair is undoubtedly the most important factor, as a tendon's main function is to transmit force. It is critical that the repaired tendon should be able to tolerate forces submitted during initiation of mobilization until healing occurs.

By increasing the number of core strands that cross the repair site, and by adding epitendinous sutures, the tensile strength of a repaired tendon is greatly improved.

Chapter 2

STUDY OBJECTIVES

2.1. General Objectives

- To test the ultimate tensile strength and stiffness of three flexor tendon repair techniques using a synthetic, non-absorbable, monofilament polypropylene suture material
- To compare the strength between an epitendinous suture and non epitendinous suture

2.2. Specific Objectives

- To determine the strength and suitability of the figure of 8 technique, in flexor tendon repair in comparison with more established repair techniques
- To establish a clinically acceptable, less complicated alternative with near similar tensile strength

Chapter 3

MANUSCRIPT

3.1. TITLE: BIOMECHANICAL EVALUATION OF FOUR STRAND FLEXOR TENDON REPAIR TECHNIQUES, USING A DOUBLE FIGURE OF 8 TECHNIQUE

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3.3 INTRODUCTION

Flexor tendon injuries are significantly common. The tendons lie close to the skin, making it susceptible to injuries in the form of lacerations caused commonly by broken glass or knives. Management of flexor tendon injuries have proven to be challenging for many reasons. Firstly, the injuries are a clinical problem and will not heal without surgical intervention. The two lacerated ends of the tendon require to be surgically brought together and held in place with a suture in order for healing to take place.

Secondly, postoperative rehabilitation requires a structured protocol, as mobilization is of functional importance. This will not only improve tendon gliding, but reduce the risk of adhesion formation. An over aggressive mobilization therapy may subject the repaired tendon to the risk of rupture, therefore a strong and durable repair is required to reduce this risk. Finally, in view of the unique anatomical structure of the tendon, which run through sheaths and pulleys, prevention of a bulky repair is important but not always possible, as this will affect the final functional outcome.

Outcomes of a tendon repair has many factors. The strength of a repair is of upmost importance, as a tendon's main function is to transmit force. Therefore it is essential that a repaired tendon should be able to withstand forces applied during initiation of range of motion exercises until healing takes place.[1] Multiple publications on different suturing techniques have been described, mostly on improving the strength of a repair.

A tendon repair with sufficient tensile strength will permit early mobilization[2], and in return prevent formation of adhesions[3], stimulate healing of the tendon[4] and clinically provide a better outcome.[5] Biomechanical studies have determined that by increasing the number of core strands, and by adding an epitendinous suture, the tensile strength of a repaired tendon significantly increases.[6]

An ideal flexor tendon repair is often described as a surgical technique which is atraumatic[7] and has a tendon anchorage of 10mm or more from the traumatic cut surface.[8] The material of the suture should be easy to handle, it should hold a secure knot[9] and it should not affect the vascularity of the tendon, and gliding motion of the tendon inside its sheath and pulleys.[10]

In recent years, double-stranded or loop sutures have been used to produce multi-strand repairs. These sutures are at an advantage as it doubles the strands across the repair site with less suture bites, simplifying the procedure. However these sutures are not readily available in most hospitals due to its higher cost.

This study compared three suture techniques using the readily available and commonly used synthetic, non-absorbable, monofilament polypropylene suture material (prolene). Comparison of tensile strength between the well-established modified four strand Modified Kessler suture technique and four strand cruciate technique in relation to the four strand double figure of 8 technique was done. The test was performed with and without an epitendinous suture.

Performing an epitendinous suture in addition to core sutures ensured that the lacerated ends meet. It has been biomechanically proven to enhance both mechanical strength and gapping resistance.[11]

This biomechanical analysis would be of a more clinical significance as the suture material used was easily available in all general hospitals across Malaysia, and the size and length of an Achilles tendon of a chicken mimicked that of a human flexor tendon.

The aim of this study was to establish a suture technique which is relatively simple, less complicated, clinically acceptable, and with a significantly strong tensile strength.This in turn would help practicing medical personnel to provide a rather fast and efficient surgical treatment of multiple flexor tendon injuries.

3.4 METHODOLOGY

MATERIALS AND METHODS

Synthetic non absorbable, monofilament polypropylene suture 3/8 circular reverse cutting needle was used. Size 4-0 for the core suture and 6-0 for the epitendinous suture. Three techniques were used, these techniques were tested with and without an epitendinous suture.

Achilles tendon of chicken was proposed for this study on biomechanical analysis, as they were cheap, readily available, and easy to harvest and did not pose as an ethical issue. After an extensive literature search, no previous study using Achilles tendon of chicken had been attempted before. The usage of chicken Achilles tendon served as a comparable model in terms of structure, size and consistency. Furthermore there has not been a study on comparison of its biomechanical properties.

In order to determine the sample size required for this study, we used the well-known software, PASS version 14. The power was set at 0.90 and its critical value alpha set at 0.05

The statistical test done was Wilks Lambda which is a quite a robust and popular test appropriate for multivariate analysis (analysis of 3 different group variables, including finding out whether differences exist within each group in repeated measures, ANOVA).

The total sample size calculated was that of 48, with 24 samples for each type of independent variable (epitendinous and non epitendinous being an independent variable each), with 8 samples used per technique.

Fourty-eight achilles tendons of 24 freshly slaughtered adult chickens that were for commercial sale were harvested and subsequently randomized. All tendons were temporary placed in a saline soaked gauze. The tendons were divided into six groups of eight. All the tendons were transacted transversely at the midpoint with a sharp surgical blade and immediately sutured, with the same surgeon performing all the repairs. Similar steps of repair were applied to all tendons, with the placement of the core suture assigned to each group, followed by the placement of peripheral sutures. All the peripheral sutures were standardized with identical purchase of 3mm from the lacerated site with six continuous needle passes, they were all tied with the same knot.

The three different types of four stand core suture techniques were the modified Kessler (figure 1), Cruciate (figure 2) and the double figure of eight technique (figure 3). The sutures of the core repairs gripped the tendons 10mm from its lacerated ends. The site of suture bite was determined by using a Vernier calliper. All repairs were tied with the same knot.

MECHANICAL TESTING

We used an Instron Table - top universal testing device (figure 4) to measure ultimate tensile strength. Each tendon was clamped at both ends at a distance of 15 mm from the repair site

The tensile force to the axis of connection was applied at a loading rate of 10mm/min. Load-to-failure curves were calculated, and measured in millimetres. The ultimate load at failure and stiffness was measured. Stiffness was measured at levels between 5N to 70 N

All the tendons were tested for ultimate load to failure, mode of failure and stiffness. Failure was defined as core suture pull-out (intact suture construct that slipped out of tendon), knot failure or suture breakage (rupture of suture)

If the core repair fails by failure at its knot, it is most probably due to inadequate tying of the knot (inferior fixation technique). If it fails by a suture pull-out, this means that a technically strong fixation cuts through the tendon. A suture breakage is self-explanatory.

Statistically significant differences between the three suture techniques were determined after performing multiple comparisons between the groups using the Tukey test. A multivariate test with wilks lambda was also conducted between the 3 techniques and its types (non epitendinous and epitendinous) to highlight the importance of an epitendinous repair. Finally a Fischer Exact test was performed to evaluate the significance of suture failure in relation with suture type. $P<0.05$ was considered significant

3.5 RESULTS

In this study, the double figure of 8 technique was surprisingly the strongest technique, this was statistically significant as well. The well-established methods of a Cruciate and modified Kessler technique when compared did not statistically show any difference in tensile strength. The significance of an epitendinous repair was statistically very well demonstrated, in which all samples required a much stronger force to fail.

In this study, majority of failures among the non-epitendinous type of sutures were due to suture pull-out, whereas failures among the epitendinous type of sutures were mostly due to knot failure. This is statistically significant ($p=0.015$) after performing the Fisher Exact Test (Table1).

Among the 24 samples with purely a core suture (nonepitendinous group), 4 samples failed via knot failure, which could be explained by a possible poor repair technique being performed for this particular samples. As all the 4 failures occurred in the modified Kessler group, this could suggest that due to the relatively more technically demanding repair technique, the quality of the knot tying technique may have been compromised.

All the repairs with an epitendinous suture, failed initially at its peripheral repair. The tensile load was then solely borne by the core repair until its own failure, which was mostly due to failure at its knot. The core sutures were then observed to fail at a higher load. The distribution of knot failure are almost equal among the three groups, indicating that during absorption of stress by the epitendionous suture at the periphery of the tendon, it is most probably a possibility that the knots for the core suture simultaneously weakness (as it is placed externally to the tendons) and gives way.

The result of a Multivariate tests performed with Wilks Lambda (Table 2) indicates that there are significant differences ($p<0.05$) between the three techniques and Types of sutures (epitendinous and non epitendinous) used. In terms of tensile strength, the tendons with an epitendinous repair recorded higher readings of superior tensile strength. The cruciate non-epitendinous group had an average reading of 19.6 newton compared to the epitendinous group which had a much stronger 45.6 newtons. The nonepitendinous modified Kessler had a reading 22.4 newtons, while the epitendinous group recorded and everage of 41.4 newtons. Finally, the nonepitendinous group for the figure of 8 technique recorded 30.3 newtons, and its epitendinous group recorded 45.7 newtons.

As reported in other studies, analysis of this study clearly demonstrates the importance of an added epitendinous suture (Table 3). The significant differences between the two types of sutures (epitendinous and non epitendinous) that resulted in failure due to maximum stress, strain and force ($p<0.05$) and the significant differences between the three techniques that resulted in suture failure due to maximum strain ($p=0.039$) and maximum stress ($p=0.024$) are also reported in this table There was no statistic difference between the three techniques in term of force.

By performing a post-hoc tukey test (Table 4), multiple comparisons for the three different suture techniques in relation to stress, strain and force were obtained. The four strand double figure of 8 technique had the highest tensile strength with an average of 38 newtons, compared to the other two methods of cruciate and modified Kessler, which both had an average of 32 newtons respectively. There is significant difference between the double figure of 8 and Cruciate techniques at maximum strain that causes suture failure ($p=0.047$), as well as significant difference between the double figure of 8 and Kessler techniques at maximum stress that caused suture failure ($p=0.018$). In comparison, analysis between the well-established four strand cruciate technique and the four strand modified Kessler technique does not show any statistical difference.

3.6 DISCUSSION AND LITERATURE REVIEW

Primary surgical repair has been the treatment of choice in managing acute lacerated tendons since the mid- 20th century. Post-surgical strength for tendon injuries are influenced by the repair technique, properties of the suture, knot security and its configuration.[12] The surgical suture technique that are used for flexor tendon repair consist of two parts, its core suture and its peripheral suture. While peripheral suture are most often similar, the number and technique for core suture often differ. Previously, a two strand repair was considered strong enough to be applied in clinical practice, however this belief was soon brought into question as multiple studies reported a high incidence in rupture rates after initiation of early active mobilization protocols[13], which only until recently, has been accepted as a gold standard in rehabilitation management.

There is still however, various conflicts and disagreements among numerous authors regarding the most ideal suture technique, and specific rehabilitation exercises that will provide the patient with the best possible functional outcome.

Therefore it is a not unexpected that multiple strand sutures have been created to meet clinical standards. While these techniques have improved the tensile strength of a tendon repair, their complex properties and techniques have led to an increase in operating time. Difficulty in the learning process may have also discouraged many in adapting these methods in their day to day clinical practice.

By increasing the number of core sutures in a repair of a lacerated tendon, the strength of the repair increases, and this permits a more active rehabilitation with less risk of rupture. This will have a positive effect as it will ultimately reduce the potential of adhesion formation. Unfortunately, a repair with higher number of core sutures will negatively affect tendon gliding by increasing resistance caused by a more bulky repair. Knots that are placed internally are beneficial in terms of reducing resistance during tendon gliding, but there are much to be concerned about regarding ischemia and acellularity which will eventually lead to delayed or incomplete healing of the tendon repair and ultimately failure by rupture.

Peripheral circumferential suture is now a mainstay of tendon repair as it ensures that the ends of the tendon meet and provide further strength and reduces the gap formation.

The characteristics of an ideal primary flexor tendon repair had been classically described by Strickland.[14] In his review, he concluded that in order for a tendon to heal well, the repair should compromise of a suture material that can be easily placed or passed through a tendon. The repair site should have minimal gapping, its tendon ends should have a smooth juncture and a well secured suture knot. This is to prevent adhesions and resistance to tendon gliding. The construct of the repair should have minimal effect with its vascularity and should be strong enough to permit the application of early motion stress throughout the process of healing.

The performance and character of differing flexor tendon repairs have been widely discussed, investigated and published, significantly adding to our understanding of the best way to suture a tendon and therefore prepare it, for the application of stress by motion. Research by Urbaniak et al, [15] and Komanduri et al, [16] have described that the resilience of a flexor tendon repair is in relation to the quantity of suture strands that cross the site of repair.

Trail et al [17] had demonstrated that after a flexor tendon repair, failure most often occurs at its suture knots. They proposed that 3–0 or 4–0 sutures were suitable to be used in a clinical setting due to easier placement and better strength. They also suggested that despite the potential for increased frictional drag on the tendon, whenever possible, it was best to locate knots outside the repair.

Mashadi and Amis [18] studied the results of difference in strength between grasping loops compared with locking loops. They concluded that grasping loops had a high failure rate and that locking loops did contribute to strength but only modestly, and the effect of higher loading could lead to gapping and failure.

Taras [19] proved that larger-caliber sutures significantly increase the strength of a repair. Where else, Soejima et al, [20] proved that there is a significant advantage in terms of strength biomechanically in dorsal rather than palmar placement of core sutures. However , despite the added strength, the more suture strands that cross the repair site, the harder and more time consuming the technique becomes, and the likelihood that the method damages the tendon, compromises its nutrition and its ability to heal decreases.

Lindsay et al, [21] indicated that gap formation at the surgical site eventually develops to be the weak link of the tendon. It alters the biomechanics of the tendon by promoting formation of adhesions which ultimately result in a reduced excursion of the tendon.

Therefore the importance of the use of a peripheral circumferential suture after the completion of a core tendon repair had been established by the findings of Diao et al, [22] they stated that epitendinous sutures would provide a 10% to 50% increase in flexor tendon repair strength with a significant reduction in gapping between the tendon ends.

Multi-strand repairs produces stronger repair, but complexity of its techniques require time and practice to master, in order to replicate a repair strength which is consistent and similar to those that are done or created in a laboratory.

The Modified kessler and cruciate techniques are well established, and its strength has been evaluated previously. The current study was performed to ascertain if the double figure of 8 technique, though simple and less complicated had sufficient tensile strength for a flexor tendon repair. To determine if the epitendinous suture is of benefit, biomechanical analysis of the core repairs with and without an epitendinous suture was performed.