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Biomechanical Study of Two Peripheral Suture Methods on Repaired Tendons

Abstract: Flexor digitorum tendon injuries are challenging conditions to manage to ensure optimal patient outcomes. While several surgical approaches with high success rates have been developed, there remains no gold standard for suture technique for the repair of flexor tendon injuries. In this study, we compared two distinct peripheral suture methods on the strength of repaired tendons. Pig flexor digitorum profundus tendons were used in biomechanical studies and the biomechanical influence on tendon repair of continuous running peripheral suture (CRPS) and continuous locking peripheral suture (CLPS), were compared, using stitch length ranging from 1mm to 5mm. In CRPS, the 1mm stitch length group displayed the highest maximum load and breaking power, which was 1.57 fold higher than the 2mm stitch length group. Pairwise comparison revealed that the 1 and 2mm groups were statistically different from the 3, 4, and 5mm stitch length groups while comparison among the latter groups was not statistically significant. For CLPS, the 1mm group exhibited consistently the highest maximum load strength and breaking power, which was twice the strength displayed by the 2mm group. Pairwise comparisons between groups showed statistical significance. For future repairs of flexor tendon injuries, 1mm stitch length is highly recommended for simple peripheral suture.

Keywords: Flexor tendon; peripheral suture; stitch length; biomechanical study

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1 Introduction

Hand injuries constitute a major proportion of injuries seen in many hospitals worldwide [1]. Of the known traumatic injuries, flexor tendon injury is very commonly observed in clinical practice, and of which cut injury represents the highest incidence. Tendon injury alone and in combination with other injuries account for 30% of hand trauma. Injury to the flexor tendon system can lead to significant morbidity for patients. The efficacy of treatment for flexor tendon injury is dependent not only on the extent of damage, but also on the choice of surgical techniques, and intraoperative non-invasive operating techniques. Up until now, the healing process after flexor tendon surgical repair has not been ideal. In particular, adhesions are hard to prevent and they often seriously impede hand functions. As such, improving the quality of the healing process post-flexor tendon surgery, and reducing or preventing the occurrence of adhesions are challenges that remain to be resolved. Tendon adhesions are attributed to factors such as the choice of incision; suture; whether or not the tendon sheath and pulley system are retained; primary vs secondary injury processing; whether or not the vinculum tendinum is damaged; and postoperative activities. All of these factors can largely influence the effectiveness of tendon repair.

Tendon suture is a complicated and meticulous surgical technique and represents one of the basic techniques of hand surgery. Numerous experimental and clinical research studies on flexor tendon injury and repair performed to date had significant emphasis on different methods of tendon repair suture[2, 3], and are classified into three categories[4]. The first type is Interrupted Suture where the suture tension parallels to the tendons of the collagen bundles and as such the repair stress could be directly exerted on the adjoining tendon ends, leading to weakened repair. The second type is modified Kessler and Tsuge's Suturing where the longitudinal suture tendon

tension is converted to paired oblique or transverse pressure, and the intensity of the repair is dependent upon the strength of the suture itself[5, 6]. The third type is Pulvertaft Tendon Weaving Technique where the suture is vertical to the tendon collagen bundles and the direction of stress, and this technique provides the strongest repair intensity [7, 8].

The tendon suture techniques described above primarily target the core suture while mechanical studies on the peripheral suture techniques have not been systematically investigated. The peripheral tendon suture was initially introduced as a method of smoothing the repair site and improving the gliding function of the tendon within the narrow synovial sheath [9]. At that time, the investigators have examined the improvement in strength that is associated with the placement of various types of peripheral sutures and found that the peripheral suture was an important component of the tendon repair and prevented early gap formation[10]. Lin and colleagues reported that the placement of a locked peripheral suture significantly augments the strength of tendon repair [11]. Diao and colleagues examined the effect of the depth of the suture placement on the strength of the peripheral repair and found that peripheral suture can strengthen the tendon repair by 10-50% [12]. In recent years, several peripheral suture methods have been developed including continuous running peripheral suture (CRPS) [13], continuous locking peripheral suture (CLPS) [14], continuous cross-stitch peripheral suture [4], and Halsted suture [15] However, in clinical practice, the burgeoning amount of research on tendon repairs has made it difficult to follow, and no gold standard has been determined for the optimal repair algorithm. In fact, it seems that repairs are usually chosen based on a combination of familiarity from training, popularity, and technical difficulty. In this study, we investigated the biomechanics of the influence of different suture stitch lengths of CRPS and CLPS on the strength of repaired tendon.

# 2 Material and Methods

2.1 Tendon sources and Suture techniques

Flexor digitorum profundus tendons were harvested from 80 adult pigs and randomly divided into ten groups with eight animals per group. Continuous running peripheral suture (CRPS) is a running, non-locked method while continuous locking peripheral suture (CLPS) is a locking

technique (Figure 1). Either in CRPS or CLPS, the 4-0 polypropylene suture was used (Prolene: Ethicon Inc., Somerville, NJ) with stitch length of 1, 2, 3, 4 or 5mm. The suture was inserted and protruded 3mm from the lacerated edges of the tendon ends, and at least 2mm deep into the tendon.

2.2 Biomechanical test and Statistical analysis

The tendon ends were fixed on the mechanical analyzer. The tendon length between grips was kept constant at 6cm, in order to eliminate the variation caused by unequal length tensile deformation. The analyzer was set to zero when the tendon was completely relaxed. After 1.0N preload was applied to the tendon, the load and displacement values were reset to zero. The tendon was then stretched at a speed of 25mm/min until the tendon ruptured. The maximum load and breaking power were recorded by the analyzer. The maximum load is defined as the peak of the curve and the breaking power is defined as the peak covered area. ANOVA and Newman-Keuls were used for the statistical analysis. $p < 0.05$ was considered statistically significant.
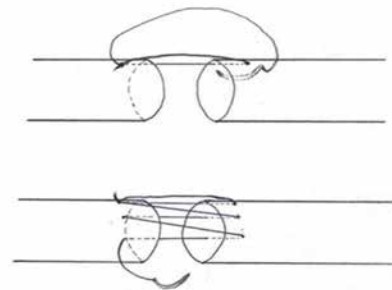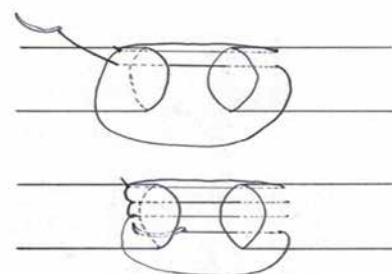

Figure 1: Illustrations of continuous running peripheral suture (CRPS) (A) and continuous locking peripheral suture (CLPS) (B)

3 Results

3.1 Maximum Load (Strength)

In the case of CRPS, the group with the 1mm stitch length displayed the highest load strength (61.47±2.58N), which was 1.57 fold higher as compared to that of the 2mm stitch length group (39.09). Pairwise comparison revealed that groups 1 and 2 mm were statistically different from groups of 3, 4, and 5 mm stitch length ($p < 0.01$) while comparison among the groups 3, 4, 5 mm did not reach statistical significance ($p > 0.05$). The 1mm group exhibited consistently the highest load strength of 84.10 for CLPS. This was almost twice the load strength displayed by the 2mm group (42.62). Pairwise comparisons between groups showed statistical significance ($p < 0.05$) (Figures 2A and B).

3.2 Breaking Power

In the case of CRPS, the group with the 1mm stitch length displayed the highest breaking power (0.695±0.083), which was 2.3 fold higher than that of 2mm stitch length group (0.302±0.04). Pairwise comparison revealed that groups 1 and 2mm were statistically different from groups of 3, 4, and 5mm stitch length ($p < 0.01$) while comparison among the groups 3, 4, 5mm did not reach statistical significance ($p > 0.05$). The 1mm group exhibited consistently

the highest breaking power of 1.027±0.047 for CLPS. This was more than twice the breaking power displayed by the 2mm group (0.430±0.028). Pairwise comparisons between groups showed statistical significance ($p < 0.05$), except for the comparison between group of 4mm and that of 5mm ($p > 0.05$) (Figures 3A and B).

4 Discussion

Suture techniques and suture strength are crucial at the early stage of tendon healing. The modified Kessler and Tsuge method is commonly used for flexor tendon repair while the central suture method plays a decisive role in tensile strength and healing process of injured tendons. However, both methods need supplemental peripheral sutures for better healing effect. In this study, continuous running or continuous locking peripheral suture (CRPS vs CLPS) was applied to surround both ends of the injured tendon so that the ingrowth of exogenous tissues could be effectively prevented, while leaving a fixed gap between the sutures to allow for the nutrition of synovial fluid to prevent tendon adhesion formation. This is important as adhesions can often impede hand functions. A successful tendon anastomosis should allow the tendon to slide freely after surgery, minimize scar formation and have sufficient tensile strength for early postoperative tendon rehabilitation [16]. It has been reported that 72% of surgeons use
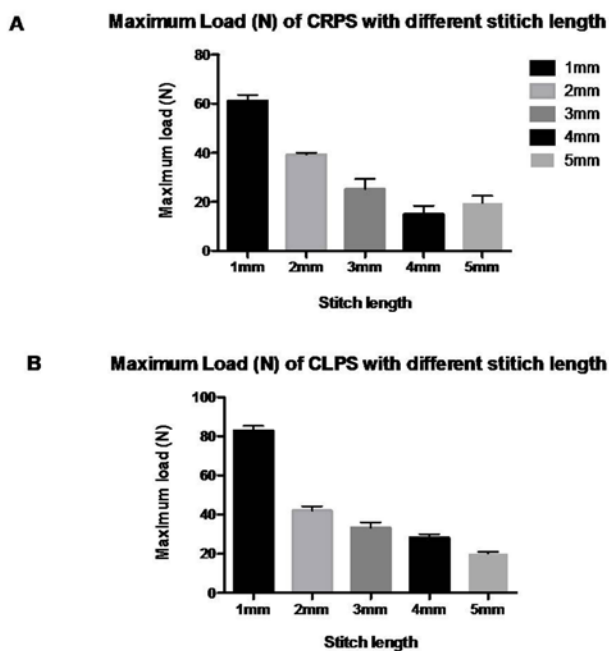

Figure 2: Comparison of Maximum load (N) of CRPS (A) with CLPS (B) with different stitch length.
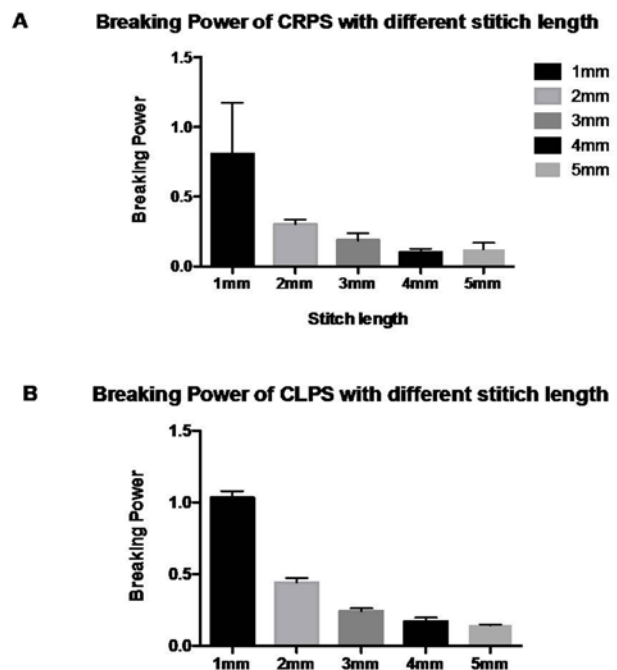

Figure 3: Comparison of Breaking Power of CRPS (A) with CLPS (B) with different stitch length.

modified Kessler method to repair flexor tendon injuries [17]. As shown in biomechanical studies for early postoperative exercise after flexor tendon injuries, the immediate tensile strength using the modified Kessler method was 41.81±6.45N, which was sufficient for the sutured tendon to actively conduct flexion without resistance. In the current study, the maximum loads (strength) were 61.47±2.58N and 39.09±0.78N in the group of CRPS with 1 and 2mm stitch length, respectively. The maximum loads (strength) were 84.10±2.50N and 42.62±2.49N in the group of CLPS with 1 and 2mm stitch length, respectively. The maximum load of these two suture methods with 1mm stitch length was >45N and therefore meet the requirements of early postoperative exercise of flexor tendons.

Furthermore, we investigated the impact of suture stitch length on the biomechanics of tendon repair. During the tendon strength test, we observed all sutures were pulled without breaking, which indicated that the measured maximum load was truly the maximum tensile strength. The results showed that the maximum loads in all 1mm stitch length groups were significantly higher than the corresponding groups with larger stitch length, indicating that more intensive stitching in the suture with small stitch length result in more friction between the suture and the tendon. We also showed that the maximum loads in both CRPS and CLPS with stitch length of 1 and 2mm were >30N. Our results would imply that the peripheral suture needle distance of 2mm would be recommended for tendon repair, if central and peripheral sutures were used. This is crucial so that the central tendon suture can provide sufficient tensile strength, and the peripheral suture can achieve the desired tensile strength with little effect on early active mobilization. However, if only simple peripheral suture is used, 1mm stitch length will be recommended because it showed significant difference when compared to other stitch length groups in terms of maximum load and breaking power. Its maximum tensile strength was >60N, which is sufficient to maintain the continuity of the tendon without prejudicing its early controlled active mobilization. Although there are multiple surgical techniques for flexor tendon repairs, no consensus has been achieved on what is the gold standard. Our current study could provide another option for flexor tendon repairs. In the future studies, the impact of stitch length on the formation of adhesions and the promotion of endogenous healing of the injured tendons will be investigated.

Conflict of interest statement: Authors state no conflict of interest

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