The Quadriga Effect Revisited: Designing a “Safety Incision” to Prevent Tendon Repair Rupture and Gap Formation in a Canine Model In Vitro

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Introduction

The canine is the most common and useful animal model for flexor tendon research because of its similarities to human tendon anatomy and structure. Postoperative care and control of the animals are still a significant challenge, as daily active motion varies from dog to dog and is difficult to control even with external fixation. Routine activities still lead to gap formation or suture rupture, thus a better control of repair loading is clearly an important aspect to consider and improve in flexor tendon research.

Previous studies have reported an alteration in which the musculotendinous junction was transected, and the tendon lengthened to prevent rupture. Others have used a radial neurectomy to prevent weight bearing. However, digit motion, decrease in tendon tension and gap formation and tendon rupture were observed, respectively, factors which might affect tendon healing.

The canine flexor digitorum profundus (FDP) is one tendon bundle until the distal forepaw, where it separates into each individual digit (Figure 1). According to the “Syndrome of the Quadriga” by Verdan, the function of one tendon will limit the excursion and function of the rest. Based on this principle, if the tension of the four digit tendons is the same, the muscle force will be transferred evenly from one bundle into each individual digit. However, tension transmission can be altered based on the excursion and laxity to their common origin. If a safety incision is made within the common bundle, tendon length and normal quadriga function might be retained, while preventing gap formation and repair rupture. At the performed incision, the force applied to the repaired tendon would be transferred to the collagen cross-links, between the intact longitudinal bindles, proximal to the level at which the tendons separate (Figure 2).

![Figure 1. a) Dissected canine FDP tendon. One tendon bundle separates into four tendons to each individual digit. b) According to the “Syndrome of the Quadriga,” muscle force is transferred evenly to the four tendons if their tension is the same (top). During flexion of the 2nd digit, with all other digits already flexed, most of the muscle force is transferred to the 2nd FDP tendon.](image)

The purpose of this study was to design a “safety incision” proximal to the FDP tendon repair site to prevent repair site rupture and maximize safety incision-to-suture strength.

Figure 2. (a) A relief incision performed proximally to the repair site to serve as a “Safety Incision” and prevent repair site failure. Variable lengths of incision were represented by Groups 1–3. When muscle force is transferred to the tendon, with all other digits flexed (white arrows), most of the force will be transferred to the 2nd digit (black arrow). (b) With only the 2nd digit in tension (black arrow) and a safety incision performed, force will be transmitted to the weak cross-link regions (shaded region).

Materials and Methods

Twenty four FDP tendons were dissected from adult mongrel dogs sacrificed for other, IACUC, approved purposes. The 2nd and 5th tendons were used for the repairs, and a relief incision, equal to the 2nd and 5th tendon widths was randomly performed at the following levels (Fig. 2):

- Group 1: 3mm proximal,
- Group 2: 4mm proximal, and
- Group 3: 5mm proximal to where the FDP separates.

Tendons were lacerated and repaired at the PIP joint. The 2nd digit of the FDP was mounted on a material testing device and pulled proximally recording force readings until the “safety incision” or repair failed (Figure 2). To measure displacement and gap formation, two markers were placed between the safety incision and between the repaired sites. A similar procedure was performed on the 5th digit.

One way ANOVA and Tukey post hoc were used to assess differences among the 3 groups for breaking strength, resistance to gap formation and differences among incision levels, respectively.

Results:

No significant difference was found in maximum “safety incision” force and suture force between 2nd and 5th FDP tendon digits with the same incision cut. There was no gap formation at the repair site in Groups 1 and 2, with failure by tearing the safety incision. All Group 3 tendons failed by repair site rupture with the safety incision intact. Mean maximum force for safety incision failure of Groups 1 and 2 were: 21.5 and 37.6 N, which accounted for 38% and 57% of the maximum force to break the repairs, respectively. No difference in maximum suture tensile strength among groups. The mean safety incision stiffness for the 3mm and 4mm groups was 11.2 and 33.3 N/mm, respectively. The mean suture stiffness (5mm incision) was 17.4 N/mm. Figure 3 shows an example of the trends experienced by the groups (Groups 1 & 2 showed similar trends).

![Figure 3. Typical force vs. displacement for the three groups (only Groups 2 and 3 are shown). (a) Once the safety incision reached its strength threshold, a noticeable displacement of the incision occurred due to tendon tear or rupture. (b) There was a constant displacement of the suture markers due to suture failure.](image)

Discussion

We explored the use of a “safety incision” concept and quadriga effect to prevent gap formation and suture failure in a canine tendon repair model. We found that all Group 3 tendons failed by repair site rupture with the safety incision intact. Although the safety incision at both 3 and 4mm distance effectively protected the repair from gap or rupture, a 4mm safety incision presented a better force threshold. Limitations of the study include looking at only border digits, looking at three incisions for the design, with the depth equal to the tendon width, and the study being in vitro. Nevertheless, we found an adequate safety incision to protect repair gap and rupture and maintain tendon tension for the FDP animal model to be about 4mm from where the FDP tendon separates.

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