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Full Length Research Paper

Biomechanical evaluation of modified Herbert screws as the suture anchor in repairing patellar ligament

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This study evaluated the biomechanical properties of modified Herbert screws as the suture anchor in repairing patellar ligament. In screw group, the damaged patellar ligaments were repaired with modified Herbert screws as the suture anchor, but they are simply sutured in suture group. The patellar ligaments in two groups were treated with above-mentioned methods, respectively. Four weeks later, the patellar ligaments were observed and measured. For goat knee joints, mean tensile force at failure was (71.13 ± 14.23) Newton (N) in the screw group and (46.09 ± 8.41) N in the suture group, respectively, (p < 0.05). Mean maximum tensile force in the screw and suture groups was (80.46 ± 11.73) N and (54.60 ± 9.79) N, respectively, (p<0.05). For hind legs of hybrid dogs, there were 5 cases of patellar ligament with complete healing in the screw group, while 2 cases in the suture group. Mean tensile force at failure was (202.99 ± 12.17) N in the screw group and (162.41 ± 15.80) N in the suture group, respectively, (p<0.05). Mean maximum tensile force was (219.69 ± 15.73) N in the screw group and (177.92 ± 15.31) N in the suture group, respectively, (p<0.05). It was a good therapeutic method to repair torn ligaments near to their insertions with the modified Herbert screws as the suture anchor.

Key words: Herbert screw, modification, ligament, repair.

INTRODUCTION

Rupture of tendon or ligament is very common in clinical practice, and must be repaired timely and effectively because the recovery of joint function depends on the curative effects of repairing (Rosenzweig et al., 2009). In order to obtain better curative effects of repairing, it is necessary to fix the broken ends to resist the static tension and be conducive to early exercise of the affected joints, and thus, the repairing technique was a decisive factor (Gerber et al., 1999). To date, a lot of effective repairing techniques were created; including Bunnell suture, end-to-side repair and the newest Locking loop suture (Pajala et al., 2009) and so on. Although, these techniques possessed good curative results, they could only repair the broken stump of tendons or ligaments, and could not be applied to repair the rupture near tendon or ligament insertion because there were no enough tissues on insertion side for suture (Bidic et al., 2009; Uchiyama et al., 2007).

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It is a great challenge for surgeons to repair ruptures of tendon and ligament near its insertion. In order to grasp the tendon stump, sutures must pass through enough tendon tissues to avoid loosening. If the tendons or ligaments were lacerated from their insertion and the distal stump tissues were too little for suture, loosening after suture repairing was unavoidable. Nowadays, a popular repairing technique that a transverse hole was drilled in the bone and then two ends of the suture through this hole were tied tightly in opposite directions could get better repairing effects. However, this technique also had many disadvantages such as surgical trauma, suture breakage resulted from friction between suture line and bone hole, reduce of bone strength, suture loosening resulted from cortical bone fracture and so on (Demirhan et al., 2003; Maffulli et al., 2008).

Thus, to repair the tendon that was broken near its insertion, we advocated fixing the tendon stump to bone and during surgical process, it was crucial to select appropriate repairing technique to avoid above-mentioned disadvantages (Gaines et al., 2009). For this purpose, we modified the Herbert screw by adding an eyelet in the distal end. After the screw was inserted, suture line could

Figure 1. A modified Herbert screw.

pass through the eyelet. Then, the proximal tendon or ligament was pulled and fixed at its insertion with two sutures. This technique had more advantages than above-mentioned techniques such as less tissue removal, less surgical trauma, less influence on local bone strength and easier operation. Because Herbert screws could increase the stress between bones fragments (Komurcu et al., 2008), this method could also fix avulsion fracture. In this study, the effectiveness of our modulation was validated by comparing it with direct ligament suture.

MATERIALS AND METHODS

Preparation of modified Herbert screws

Modified Herbert screws were made with standard Herbert cannulated screw design. The diameter of screw thread was 4.0 mm. There was 3.0 mm extension bolt at the screw head with 1.2 mm eyelet. The diameter of the extension bolt was the same as the screw root. Suture line could pass through this eyelet and the proximal tendon or ligament could be sutured and pulled to close the insertion. The total length of the screw was 23 mm (Figure 1).

Samples and animals

Twenty-two fresh goat knee joints without skin were purchased from meat processing factory, including intact distal femur, proximal tibia, patella and patellar ligament. These knee joints were randomly divided into two groups: screw group and suture group. 11 hybrid dogs (6 - 1 0 months old, 18 - 20 kg) purchased from a laboratory animal center were used for experiments *in vitro*. All procedures of this study were approved by Ethics Committee of our hospital.

Modeling of desmorrhaphy for torn patellar ligament

Twenty-two fresh goat knee joints, the hind legs were randomly divided into two groups: screw group and suture group, and each group contained 11 knee joints. Twenty-two hind legs of 11 hybrid dogs were randomly divided into two groups: screw group and suture group, and each group contained 11 hind legs. Intravenous anesthesia was performed in all animals with ketamine (5 mg/kg). After unhairing, the hind legs were sterilized and covered with sterile surgical towel, knee joints were dissected longitudinally to expose patellar ligament and tibial tubercle. In the suture group, patellar ligament were cut horizontally at 6 mm proximal to tibial tuberosity and two ends were sutured with 0-strand by modified Kessler method. In the screw group, patellar ligament were cut at the same site. At 3 mm distal site from its insertion, 2.5 mm hole in diameter was drilled at direction of 45˚ angle inclined to capitulum and then a modified Herbert screw was inserted in this hole. According to the modified Kessler method, the proximal ligaments were sutured with 0-strand passing through the eyelet at the end of the screw.

The incision was closed and then dressings were covered and changed regularly. Two weeks after operation, sutures out were performed. All animals were sacrificed four weeks after operation. Healing status of patellar ligament in each case was investigated. The standard of complete healing of patellar ligament was that, there was no visible gap in repairing site and the ligament ends were completely continued. Animals with ligament adhesions or completely separated were excluded. Whole knee joints between femur and middle tibia were cut and then measured by biomechanics assay. The goat’s knee joints were treated with same method and then measured by biomechanics assay.

Biomechanics assay

Femur and tibia were fixed by the standard cartridge of material tester (SHIMADZU, AG-20KNA). Material tester was adjusted to no tensile force labeled as zero and tensile force was elevated gradually from 30 N (5 mm/1 min). The instantaneous failure tensile force and the maximum tensile force of sutured tendon were measured.

Statistical analysis

All statistical analyses were performed with SPSS version 13.0 statistical software. The differences between goats and dogs were compared with *t*-test. All *P*-values were two-sided and $P<0.05$ was considered statistically significant.

RESULTS

Desmorrhaphy of torn patellar ligament in goats

For goat knee joints, the mean instantaneous failure tensile force was (71.13 ± 14.23) N in the screw group and (46.09 ± 8.41) N in the suture group, respectively, and there was significant difference between the two groups ($t = 0.122$, $p < 0.05$) (Figure 2). The mean maximum tensile force in the screw and suture groups was (80.46 ± 11.73) N and (54.60 ± 9.79) N, respectively, and there was also significant difference between two groups ($t = 0.622$, $p < 0.05$) (Table 1 and Figure 2).

Desmorrhaphy of patellar ligament in dogs *in vivo*

No death, wound infection or worse healing was observed in dogs after operation. All postoperative dogs walked with

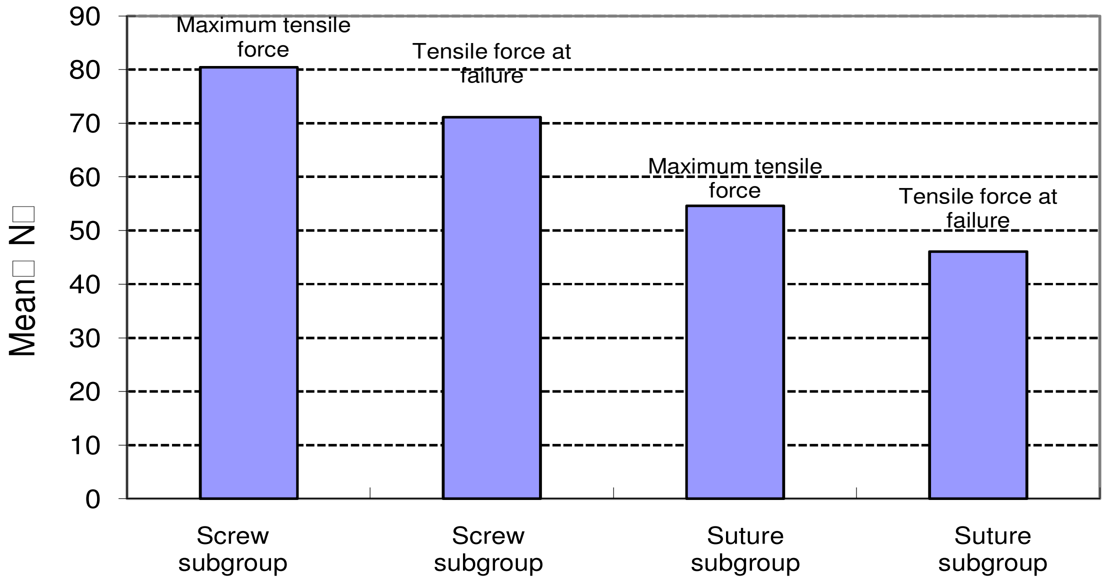

Figure 2. In the goat knee group, the maximum tensile force and tensile force at failure in the screw subgroup were both greater than the suture subgroup.

Table 1. The results of biomechanical test.

	Goat screw subgroup		Goat suture subgroup		Dog screw subgroup		Dog suture subgroup	
	Max (N)	**Rupture (N)**	**Max (N)**	**Rupture (N)**	**Max (N)**	**Rupture (N)**	**Max (N)**	**Rupture (N)**
Mean ± SD	80.46±11.73	71.13±14.23	54.60±9.79	46.09± 8.41	219.69± 15.73	202.99 ± 12.17	177.92 ± 15.31	162.41± 15.80

different degree of limp, which gradually disappeared from one week after operation and the latest recovery was at third week. No signs of breakage of the suture were observed and all canines could straighten legs. There were 5 cases of patellar ligament with complete healing in the screw group, while 2 cases are in the suture group. Most of the cases in the suture group did not obtain complete healing. Biomechanics assay revealed that, there was significant difference between the screw group and the suture group. The mean momentary failure tensile force was (202.99 ± 12.17) N in the screw group and (162.41 ± 15.80) N in the suture group, respectively, with statistic difference ($t = 0.317$, $p < 0.05$). The mean maximum tensile force was (219.69 ± 15.73) N in the screw group and (177.92 ± 15.31) N in the suture group ($t = 0.680$, $p < 0.05$) (Figure 3).

DISCUSSION

In clinical practice, the rupture of tendon or ligament might occur at its middle site, insertion site or so called avulsion fracture. It was most difficult to deal with the breakage at the insertion, because there were no enough tendon or ligament tissues for suture. The premise of healing of tendon or ligament was the connection of broken ends by suture strands, which needed enough tendon or ligament tissues for strands to cross and fix (James et al., 2008). If the breakage occurred at the insertion, there was no basis for healing because of little tendon or ligament tissues, which was confirmed by the results of suture group in this study. In order to mimic the breakage at insertion, we cut ligament near the insertion. The earliest breakage occurred at one side of the suture part near the insertion. In fact, such breakage was the loosening of suture strands from ligament. Our animal experiments also showed that the number of cases of healing of ligament in the suture group was less than the screw group.

In clinical practice, drilling hole near the insertion could provide secure adhesion for suture and solve above-mentioned problems (Caldwell et al., 1997). However, the major disadvantage of this method was surgical trauma. As bone tissues were osseous texture, drilling a transversal hole needed to dissect much soft tissues at two sides. Besides, in order that, suture strands could conveniently cross the hole, it was necessary to push away surrounding soft tissues for much space, which would further aggravated tissue damage. Thus, we think of modulation of screw so as to provide secure adhesion for suture. Screws were fixed in bone by screw threads and

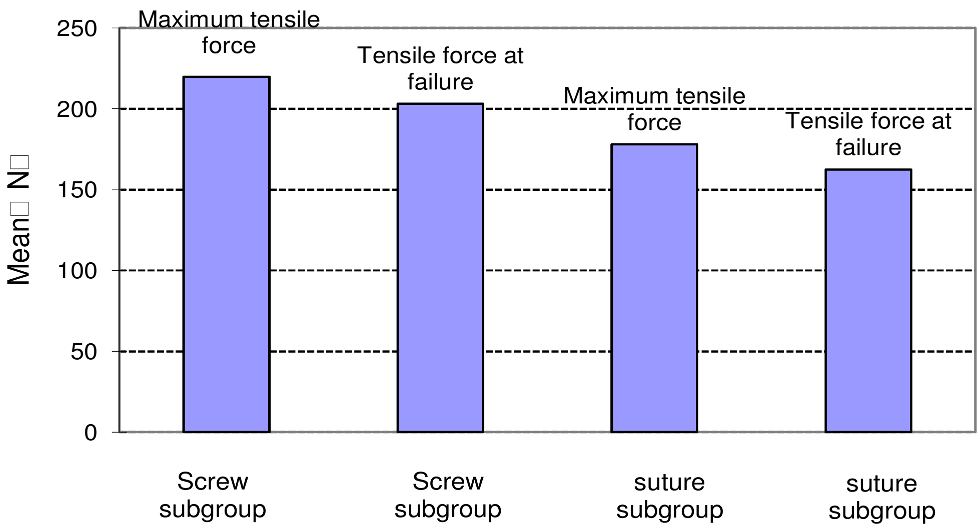

Figure 3. In the dog knee group, the maximum tensile force and tensile force at failure in the screw subgroup were both greater than the suture subgroup.

the anchoring strength was much larger than the anti-tension capability of suture strands, because all breakage occurred in suture line and no screw breakage or pull-out was found in this study. As screws could provide enough adhesion for suture line, our results revealed that the instantaneous strength and the largest tension bearing by the suture in the screw group were significantly larger than the suture group.

Herbert screw could treat ligament avulsion fracture because the pitch of its two ends was different and it could reliably fix bone fragments (Herbert et al., 1992; Sharma et al., 2008). However, when avulsed bone fragments were too small and thin to make reliable fixation, other ways which could improve the fixation effect were indispensable. Based on above-mentioned analyses, we modified Herbert screws to ensure that; it could not only fix bone fragments but also could provide adhesion for suture. At present, suture anchors are widely used and they can provide enough adhesion for suture, but they can not fix avulsed bone fragment (Brockmeier et al., 2009; Rossouw et al., 1997). Thus, compared with our modified screws, the application extent of suture anchors may be limited.

In our study, two experiments used two kinds of animals according to the ethics of animal experiment. Knee joints of goats were used in the *ex vivo* experiment, while knee joints of canines were used the *in vivo* experiment. The aim of the *ex vivo* experiment was to investigate the strength of patellar ligament after suture, while the *in vivo* experiment was made to study the healing process and strength of patellar ligament after suture, using two methods. Data of each experiment were analyzed separately, instead of comparable analysis. So, although, we used two kinds of animals, it did not affect our study and our results are reliable.

In conclusion, the modified Herbert screw may be a good therapeutic method to repair torn ligaments near to their insertions. Future work will be desirable to test whether this screw was valid to directly repair tendon injury with an avulsion fracture by fixing the fracture fragment.

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