Whether Sutures Reduce the Graft Laceration Caused by Interference Screw in Anterior Cruciate Ligament Reconstruction a Biomechanical Study in Vitro

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Research Article

Keywords: graft laceration, interference screws, suture, anterior cruciate ligament reconstruction, biomechanical study

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Whether sutures reduce the graft laceration caused by interference screw in anterior cruciate ligament reconstruction? A biomechanical study in vitro

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ABSTRACT

Background: Interference screw is commonly used for graft fixation in anterior cruciate ligament (ACL) reconstruction. However, previous studies had reported that the insertion of interference screws significantly caused graft laceration. The purpose of this study was to determine whether sutures reduced the graft laceration from the insertion of interference screws in ACL reconstruction.

Methods: Porcine tibias and bovine extensor tendons were used for establishing a knee model of ACL reconstruction in vitro. The ends of grafts were sutured using three different sutures, including the bioabsorbable, Ethibond and ultra-high molecular weight polyethylene (UHMWPE) sutures. Poly-ether-ether-ketone (PEEK) interference screws were used for tibial fixation. Biomechanical tests were performed to investigate the protective effects of different sutures on grafts.

Results: All prepared tendons and bone specimens showed similar characteristics (length, weight, and pre-tension of the tendons, tibial bone mineral density) among all groups ($P > 0.05$). The biomechanical tests demonstrated that PEEK interference screws significantly caused the graft laceration ($P < 0.05$). However, all sutures (the bioabsorbable, Ethibond and UHMWPE sutures) did not reduce the graft laceration in ACL reconstruction ($P > 0.05$).

Conclusions: PEEK interference screws significantly weakened the biomechanical properties of grafts during tibial fixation in ACL reconstruction. Absorbable, Ethibond and UHMWPE sutures did not provide protective effects on grafts during ACL reconstruction.

Keywords: graft laceration, interference screws, suture, anterior cruciate ligament reconstruction, biomechanical study

Introduction

Anterior cruciate ligament (ACL) plays an essential role in knee stability. ACL deficiency might cause meniscus tear and articular cartilage degeneration, which seriously affects the function of the knee joint [1]. The goals of surgical reconstruction of ACL ruptures are to increase the functional stability of the knee joint and decrease secondary damage to meniscus and articular cartilage [2-4].

Hamstring tendon autograft has become an increasingly popular choice for ACL reconstruction [5, 6]. Interference screw is widely accepted for graft fixation, which provides direct fixation by compressing the graft against the wall of the tibial tunnel and improves the osteointegration of graft and bone [7, 8]. However, significant concerns regarding the usage of interference screws are graft laceration and the substantial loss of fixation strength [9]. Zantop et al. [10] reported that interference screw insertion leaded to a macroscopic damage to ACL graft. Correspondingly, several fixation methods are devised to decrease graft damage, such as the sheath equipment outside the screw [11] or the use of expandable interference screw [12].

During ACL reconstruction, suturing the free ends of ACL grafts in a whipstitch fashion is a simple procedure, which helps surgeons to handle the graft and maintain an equal tension among the graft strands [13]. Previous studies had demonstrated that suturing the free ends of the graft significantly affected the biomechanical properties of graft-bone complex [14, 15]. The related mechanism is that sutures improved the engagement of the interference screw and grafts, which resulted in better fixation strength within the tibial tunnel [15, 16]. Another possible mechanism is that sutures used for suturing the ends of grafts provide protective effects on grafts, which reduces tendon fiber damage from the screw insertion and keeps the integrity of graft. However, this hypothesis has not been validated.

Therefore, we designed this study to determine whether sutures could decrease graft laceration caused by interference screw in ACL reconstruction. We hypothesized that sutures might provide protective effects on ACL grafts and decreased tendon damage during tibial fixation.

Methods

This study protocol was approved by the ethics committee of our hospital.

Experimental materials and grouping

Fresh-frozen porcine tibias (mean age, 12 ± 2.1 months) and bovine extensor tendons were used in our study. Specimens were obtained from Laboratory Animal Center of Lanzhou Veterinary Research Institute. Porcine tibias have shown similar biomechanical properties with the adult human knees [11, 17]. And bovine extensor tendons have similar viscoelastic, structural and material properties to human tendons [18]. Both were stored at -20 ° C. The grafts were randomly divided into five groups: the non-fixed group (without screw intervention, n = 10), the non-sutured group (screw intervention, n = 10), the absorbable suture group (absorbable suture + screw intervention, n = 10), the Ethibond suture group (Ethibond suture + screw intervention, n = 10) and the UHMWPE suture group (UHMWPE suture + screw intervention, n = 10). Three kinds of suturing materials were used in the suture groups: bioabsorbable suture [VICRYL Plus, 2.0, ETHICON Inc.], Ethibond suture [ETHIBOND EXCEL, 2.0, ETHICON Inc.] and ultra-high molecular weight polyethylene suture [UHMWPE, 2.0, Arthrex Inc.]. All sutures were of standard Pharmacopeia size (No. 2).

Graft and bone preparations

The tibias and tendons were thawed to room temperature 12 hours before specimen making. A single-stranded tendon was trimmed to a length of 200 mm (Figure 1A), and then folded to produce a double-stranded graft with 8.0 mm in diameter and 100 mm in length (Figure 1B). Tendons were weighed to obtain similar characteristics for grafts. The length included 30 mm for free from the end of the graft and 30 cm for screw fixation. In the three suture groups, the ends of grafts were sutured with an absorbable, Ethibond, or UHMWPE suture in a standard whipstitch fashion [stitch number (n = 6), length (30 mm)]. Then grafts were wrapped in 0.9% saline-soaked gauze until use.

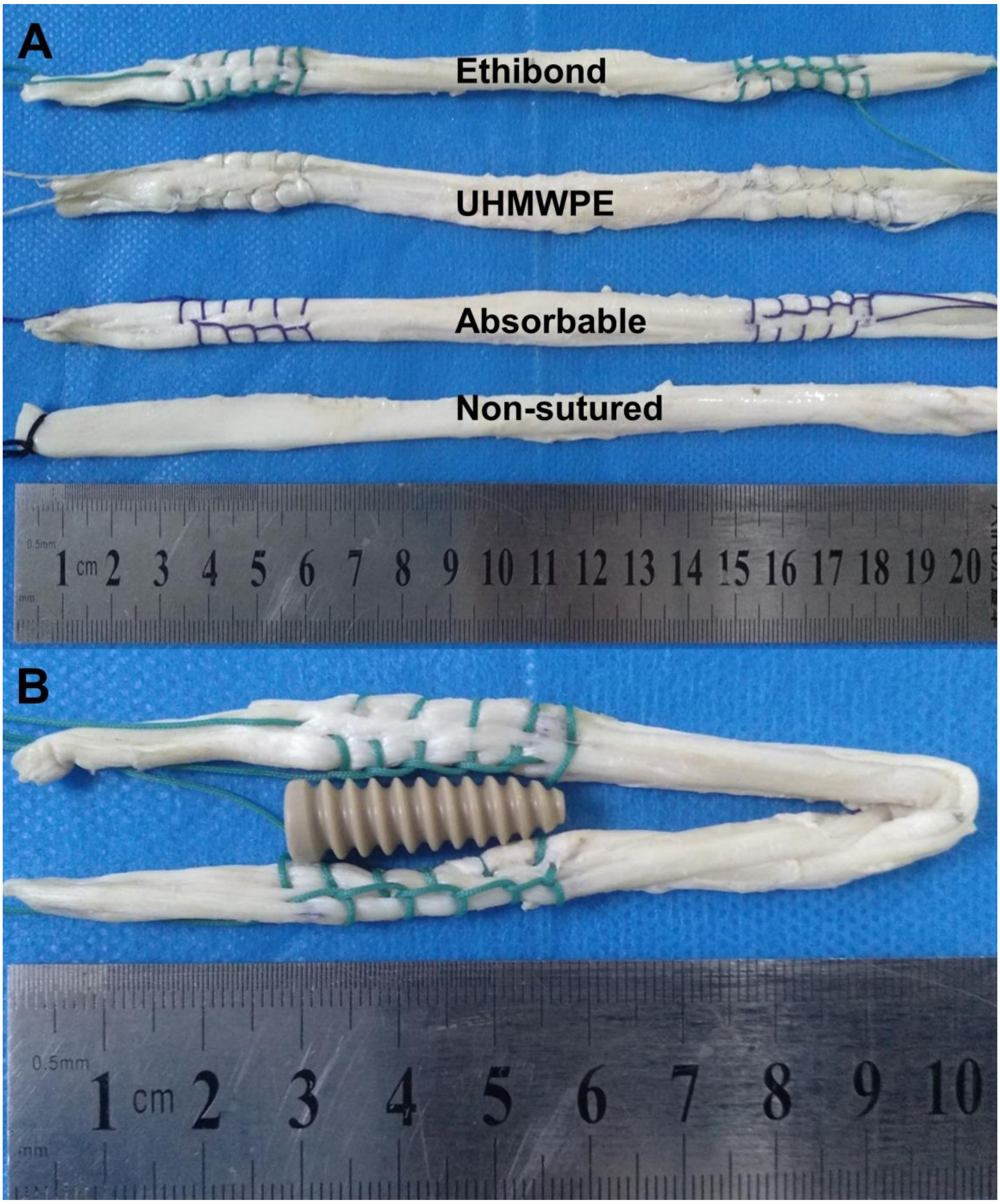

Figure 1. Preparations for grafts: (A). the prepared graft specimens in single strand with 20 cm in length; (B). an example of the Ethibond sutured graft specimens in double strands with 8.0 mm in diameter and 10 cm in length, the middle part of graft was sutured for 30 mm for the fixation of interference screw.

After graft preparation, a porcine tibia was matched with graft to undergo the following preparation. A 2.0 mm Kirschner wire was inserted in a site that located in the medial 1 cm of tibial tubercle, approximately 2.5 cm below the tibia plateau, to the center of ACL tibial footprint guided by a 55° ACL device [19, 20]. Then an appropriate-sized reamer was used to build an approximately 8*40mm tibial tunnel along the guide pin. The bone mineral density (BMD) of tibias was measured using dual-energy X-ray absorptiometry to eliminate the impact of BMD on biomechanical tests.

Study contents and fixation techniques

In the non-fixed group, grafts received no intervention (the blank control group). In the non-sutured group, grafts were not sutured but received one single insertion of an PEEK interference screw. In the suture groups, the ends of grafts were sutured using an absorbable, or UHMWPE suture, and then received the intervention with an interference screw. A poly-ether-ether-ketone (PEEK) (Arthrex Inc., USA) interference screw was used for tibial fixation in ACL reconstruction. To achieve a central fixation of the screw, an interference screw was inserted between the graft and the tunnel along a guide wire until the screw tail aligned with anterior tibial cortex [21]. After screw insertion, the tibia was split with a manual saw, and the graft was retrieved. This ensured that the graft was only damaged once by single insertion of screw. Lastly, sutures were carefully removed. Above procedures were completed by one surgeon team collaboratively.

Biomechanical test

The graft was taken out for a biomechanical test using an electronic universal testing machine (Shimadzu, AG-X series vertical machine, Japan). Graft laceration was assessed by a pull-to-failure loading test as previous studies reported [10] (Figure 2). The fixation length of distal and proximal parts for the clamps is about 20 mm.

The end of fixation part is about 5 mm to the sutured grafts (Figure 3). We use a software (Trapezium X, Shimadzu Limited, Japan) for data collection. All grafts were preloaded from 10 to 50 N at a frequency of 0.1 Hz for 10 cycles [17, 22]. Subsequently, grafts were loaded at 10 mm/min to failure. Tensile stiffness (N/mm), energy at failure (J), and the ultimate load (N) were recorded. Stiffness was calculated from the raw data of the load-elongation curve.

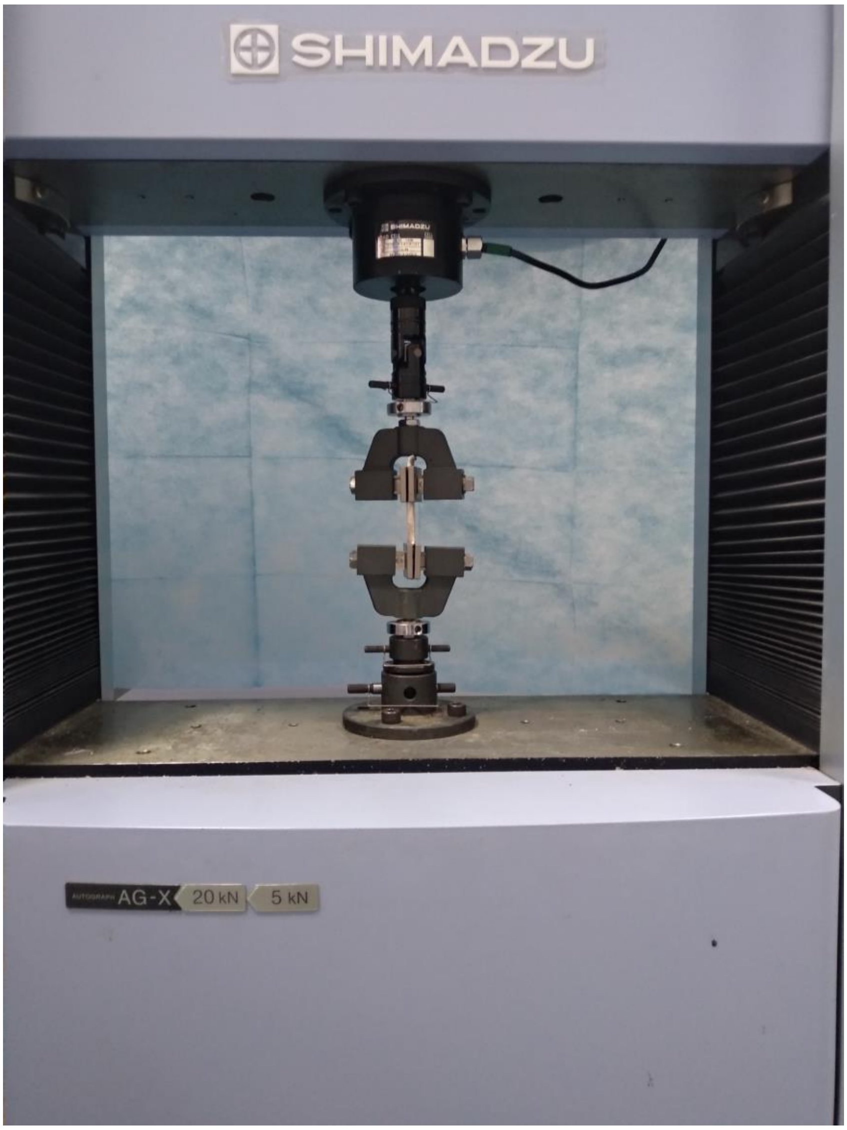

Figure 2. The biomechanical test for evaluation of graft laceration.

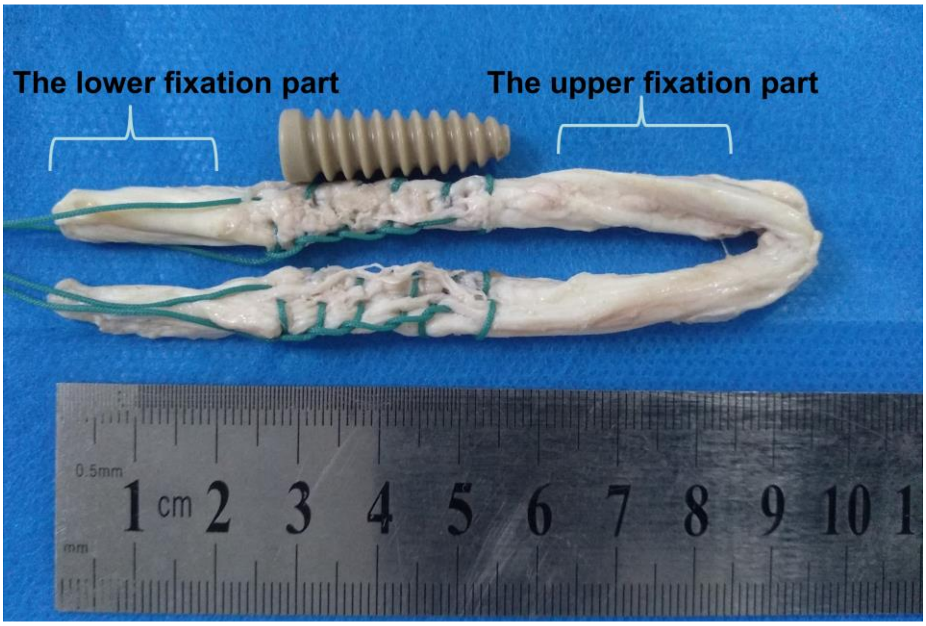

Figure 3. The fixation parts for the upper and lower clamps in the biomechanical test.

Statistical analysis

All statistical analyses were performed with SPSS Statistics 22.0 (SPSS, Inc., Chicago, IL, USA). The mean differences between groups were assessed by one-way analysis of variance (ANOVA). $P < 0.05$ was used to determine statistical significance.

Results

The basic characteristics of the grafts and tibias

The porcine tibias and bovine grafts showed similar basic characteristics. There were no significant differences in graft length, weight, pre-tension, and tibial BMD among groups ($P > 0.05$).

Outcomes of the biomechanical test

Graft laceration

In order to quantitatively investigate the graft laceration, the biomechanical comparisons were performed in the non-fixed and non-sutured groups. The results found that the ultimate failure load in the non-sutured group was significantly decreased than that in the non-fixed group (543.74 ± 101.78 N vs 406.93 ± 108.42 N, $P < 0.05$).

Protective effects of sutures on grafts

Figure 4A showed the grafts prepared for the insertion of interference screws, and Figure 4B showed obvious damage to the tendon structure after the insertion of screws. The biomechanical tests showed that the ultimate failure load was 406.93 ± 108.42 N in the non-sutured group, 416.61 ± 66.29 N in the bioabsorbable suture group, 422.08 ± 111.22 N in the Ethibond suture group, and 420.09±99.32 N in the UHMWPE suture group respectively. Though the ultimate failure load was slightly increased in the suture groups, no statistical differences were found compared with the non-sutured group ($P > 0.05$). Moreover, no differences were found in terms of tensile stiffness and energy at failure ($P > 0.05$) among these 4 groups (Table 1).

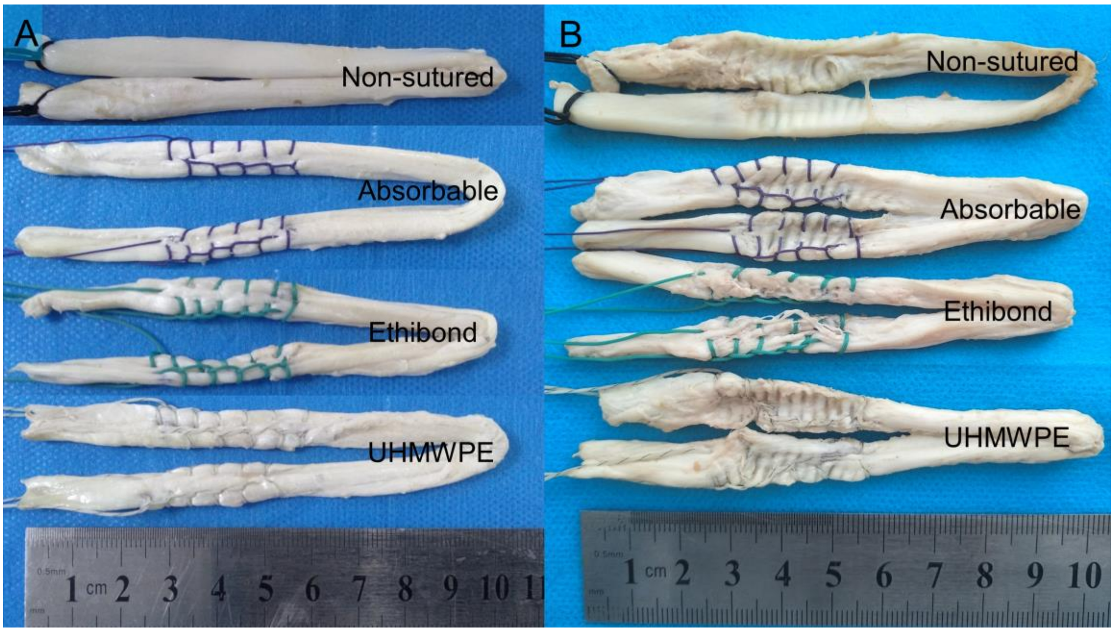

Figure 4. The comparison of grafts sutured using different sutures before and after one single insertion of a PEEK interference screw: (A). before insertion of a PEEK interference screw; (B). after insertion of a PEEK interference screw.

Table 1. The biomechanical properties for graft laceration and protective effects tests

Group	Tensile Stiffness (N/mm)	Energy at Failure(J)	Ultimate Failure Load(N)
Non-fixed group	46.34±13.01	4.19±1.68	543.74±101.78
Non-sutured group	47.48±13.22	3.12±1.29	406.93±108.42*
Bioabsorbable suture group	44.63±15.69	3.19±0.85	416.61±66.29†
Ethibond suture group	49.83±11.92	2.94±1.23	422.08±111.22†
UHMWPE suture group	47.83±9.42	3.34±1.09	420.09±99.32†

* Compared with the non-fixed group, $P < 0.05$; † Compared with the non-sutured group, $p > 0.05$. Above data are shown as means ± standard deviations.

Discussion

This study was performed to determine whether sutures reduced graft laceration during tibial fixation in ACL reconstruction. The most important finding of this study was that sutures (absorbable, Ethibond and UHMWPE sutures) used for suturing ACL grafts in a whipstitch method did not provide protective effects on grafts.

Most biomechanical tests have shown that metallic or bioabsorbable interference screws provide sufficient fixation strength [23-25]. However, the insertion of interference screws during ACL reconstruction significantly leaded to graft laceration. Sawyer et al.[9] reported that interference screws weakened the biomechanical properties of the ACL graft, which resulted in less ultimate load, yield load and stiffness. Zantop et al. [10] demonstrated that the titanium interference screw may lead to more tendon damage in comparison with the biodegradable interference screws. The yield load of specimens in the biodegradable group (714.0 ± 333 N) was statistically higher than that of specimens in the titanium screw group (67.3 ± 44 N) ($P < 0.05$). In our study, we used PEEK interference screws for tibial fixation, and the outcomes showed that PEEK interference screws caused significant damage to ACL grafts. After one single insertion of a PEEK interference screw, the ultimate failure load of the ACL graft in the non-sutured group was significantly decreased by approximately 25% compared with the non-fixed group.

During graft preparation, sutures are usually used for obtaining an even tensioning and equal distribution of forces between the strands of grafts while performing tibial fixation[13]. Moreover, sutures on the surface of grafts might decrease the cutting damage from the insertion of interference screws. In this study, we used three kinds of suturing materials for suturing the fixation part of the ACL grafts to investigate whether sutures provide a protective effect on grafts. For the measurement of graft laceration, we used an indirect method (a load-to-failure test) to quantitatively evaluate the graft damage as recommended by Zantop et al. [10]. As reported in other studies [16, 26, 27], the ultimate failure load was selected as the most representative value of fixation failure. Interestingly, our results demonstrated that, the grafts sutured using the bioabsorbable, Ethibond or UHMWPE suture showed similar ultimate failure load compared with that in the non-sutured group. Based on this result, our hypothesis that suturing the fixation part of the ACL graft decreased the graft laceration from the insertion of interference screws was not supported. One possible explanation was that, although different sutures were used for suturing the grafts, but the same suturing method (a whipstitch fashion) produced a similar interrupted space on the surfaces of tendon. The interference screw may damage tendon fiber through the interrupted space.

The bioabsorbable and Ethibond sutures are two of the most commonly used sutures for ACL graft preparation. Ethibond sutures are made of braided polyester with higher strength than bioabsorbable sutures. The UHMWPE suture is a new suture material, which has greater tensile strength than Ethibond sutures [28, 29]. Wright et al. reported that the biomechanical properties of the UHMWPE suture would be maintained even when they are partially damaged [30]. Despite UHMWPE sutures showed improved biomechanical properties, our results did not found that this suture significantly reduced graft laceration compared with the bioabsorbable and Ethibond sutures. One possible reason was that the material of UHMWPE sutures determines that it is more likely to slip than the other two sutures. Previous studies reported that knot slippage was more frequently occurred when knots tied using the UHMWPE sutures while it is under cyclic testing, and Ethibond sutures was the least likely to slip[28, 31].

During the ACL reconstruction, surgeons are more concerned about the fixation strength of ACL grafts. As previous studies [15, 16] had reported the effect of graft suturing on the pullout strength, we did not perform similar tests in our study. Prado et al. [18] demonstrated that suturing the graft may result in an increase in yield load of about 50%. Hoher et al.[15] found that suturing of the graft construct significantly increased ultimate failure load by about 30%, but superior outcomes was not confirmed in response to cyclic loading. Therefore, they concluded that, although suturing grafts improved the ultimate failure load of the graft construct, a more aggressive rehabilitation protocol was not allowed for patients after surgery.

Limitations

Several limitations should be addressed to this study. Though porcine bone and bovine tendons have been frequently considered similar to human knees with regard to BMD and biomechanical properties [11, 17], it is difficult to completely imitate the complex knee environment of human [32]. Secondly, it should be noted that, we only assess the influence of the interference screw on the ACL graft itself and does not evaluate the fixation strength to which the ACL is subjected in vivo, as previous studies had reported the effects of suturing the grafts on pull-out strength of tibia–graft constructs. Third, the biomechanical test on the grafts in vitro may be different with the forces on the graft during knee movement. Despite the above limitations, our results may help to understand whether sutures reduced the graft laceration during tibial fixation. In the clinical practice, whipstitching the grafts does not decrease the tendon damage from interference screws.

Conclusions

Using an in vitro model, our biomechanical study suggested that the biomechanical properties of grafts were significantly weakened while inserting a PEEK interference screw in ACL reconstruction. Suturing the ends of the grafts using different sutures (absorbable, Ethibond and UHMWPE sutures) did not decrease the graft laceration caused by interference screws.

List of abbreviations

ACL: anterior cruciate ligament reconstruction;

UHMWPE: ultra-high molecular weight polyethylene;

PEEK: Poly-ether-ether-ketone;

BMD: bone mineral density;

ANOVA: one-way analysis of variance

Ethics approval and consent to participate

Ethics approval for this study (D2020-10) was obtained from the Institutional Review Board of Lanzhou University Second Hospital, Lanzhou, Gansu Province, China.

Consent for publication

Not applicable.

Availability of data and materials

The data and materials in this paper are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

Y.T., L.D. and Y.X. designed the study; Y.T., L.D., X.Z., H.W., H.H., M.W. and S.Z. collected the data; Y.T., L.D., X.Z., H.W., M.W., and S.Z. analyzed and interpreted the data; Y.T., L.D., X.Z., H.W., H.H. and Y.X. wrote the initial draft; Y.T., L.D., X.Z., H.W., H.H., M.W., S.Z. and Y.X. ensured the accuracy of the data. All authors read and approved the final manuscript.

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Figures

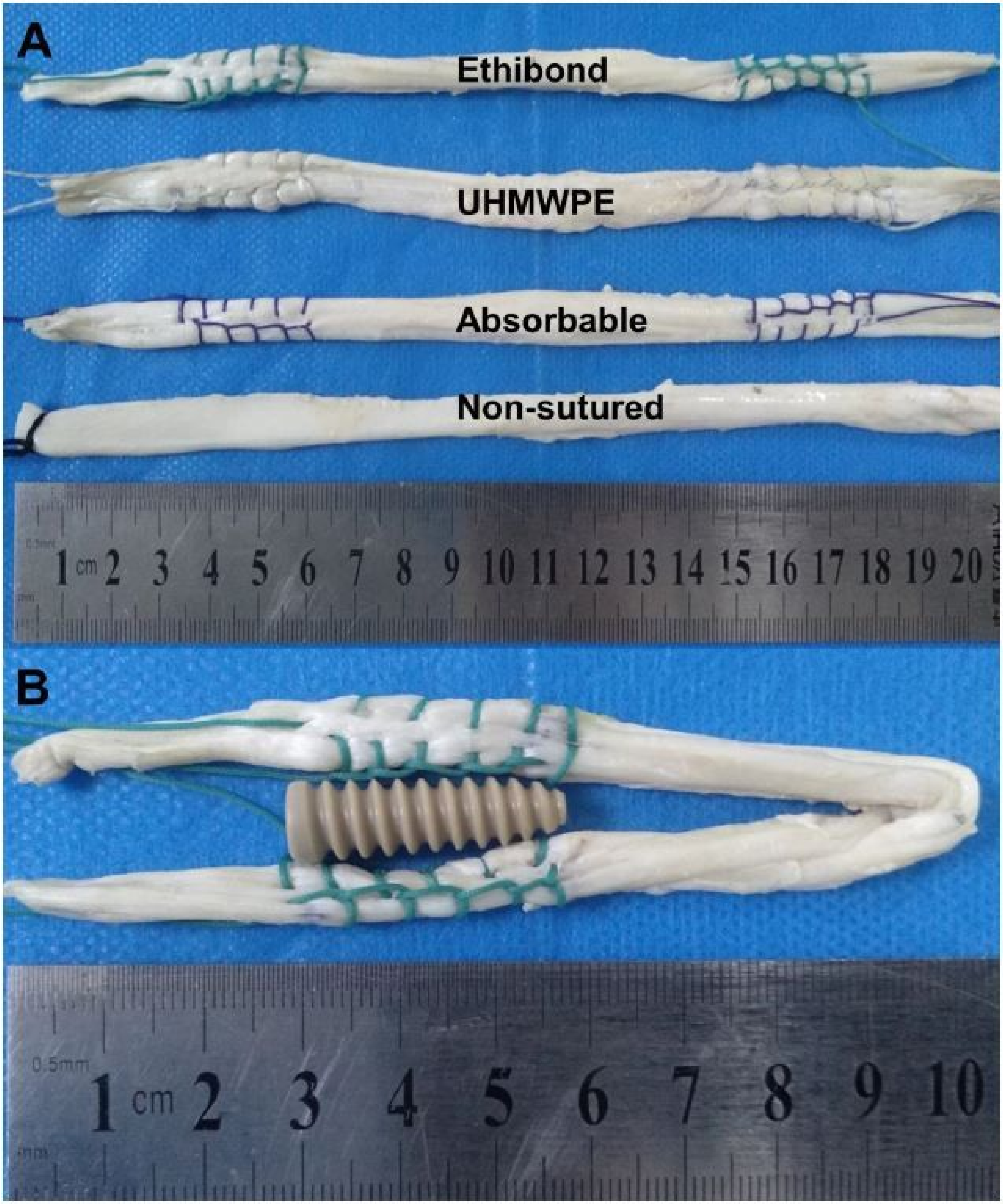

Figure 1

Preparations for grafts: (A). the prepared graft specimens in single strand with 20 cm in length; (B). an example of the Ethibond sutured graft specimens in double strands with 8.0 mm in diameter and 10 cm in length, the middle part of graft was sutured for 30 mm for the fixation of interference screw.

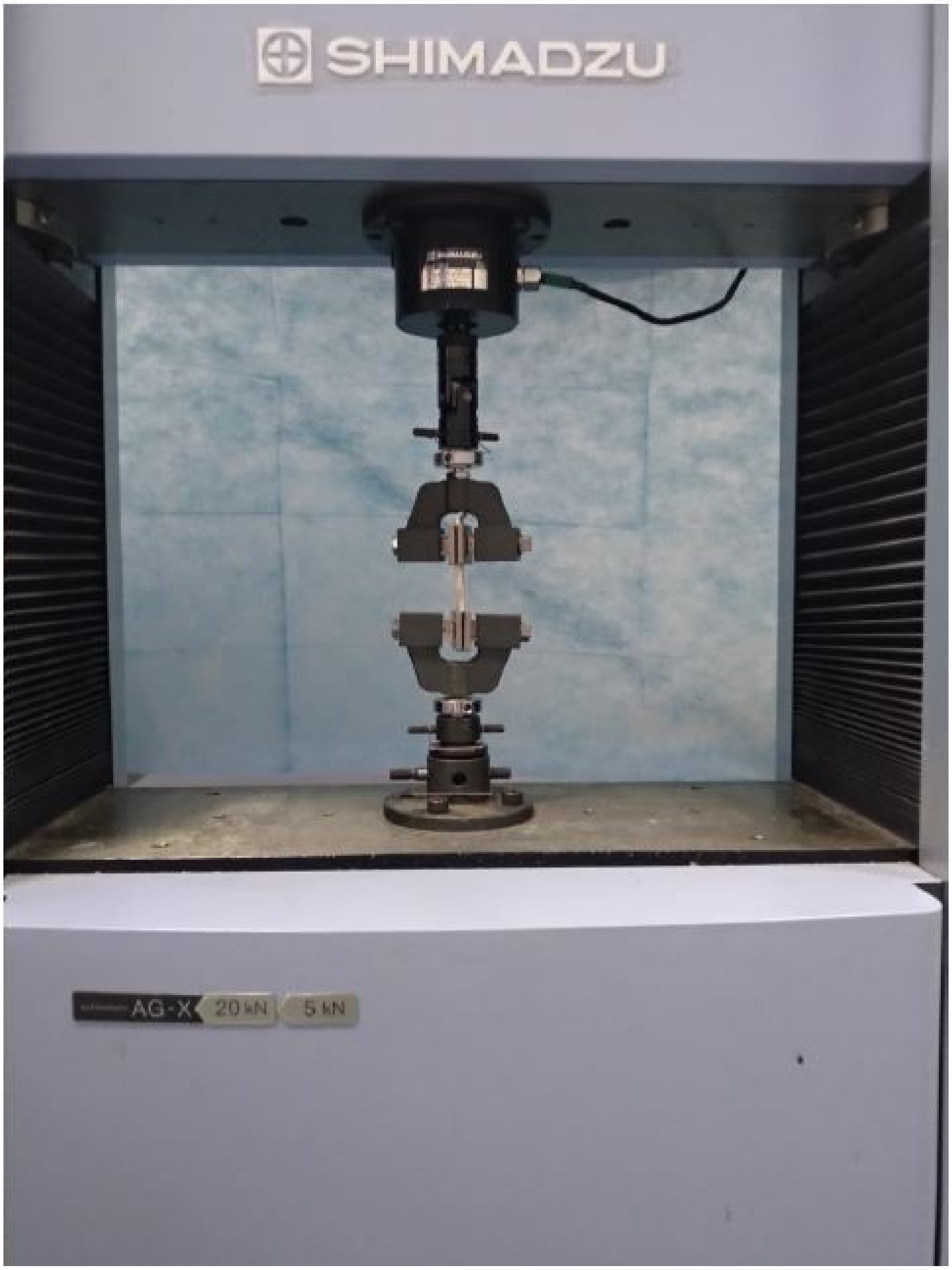

Figure 2

The biomechanical test for evaluation of graft laceration.

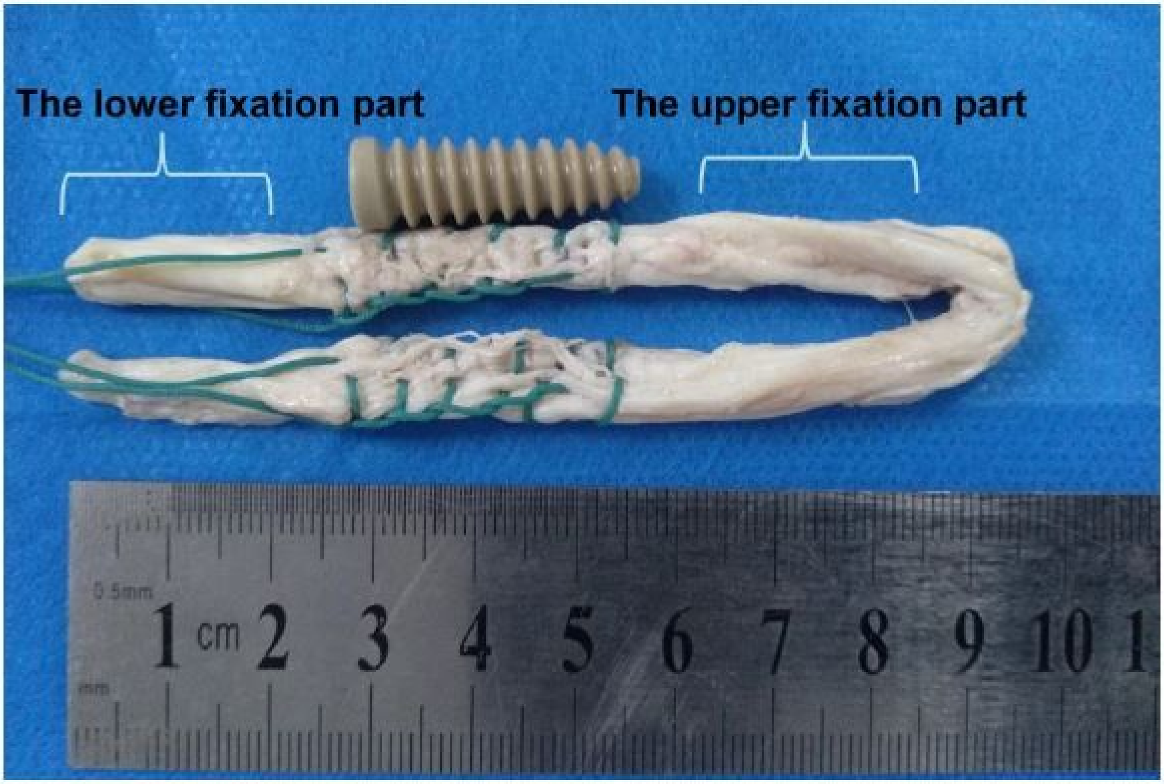

Figure 3

The fixation parts for the upper and lower clamps in t he biomechanical test

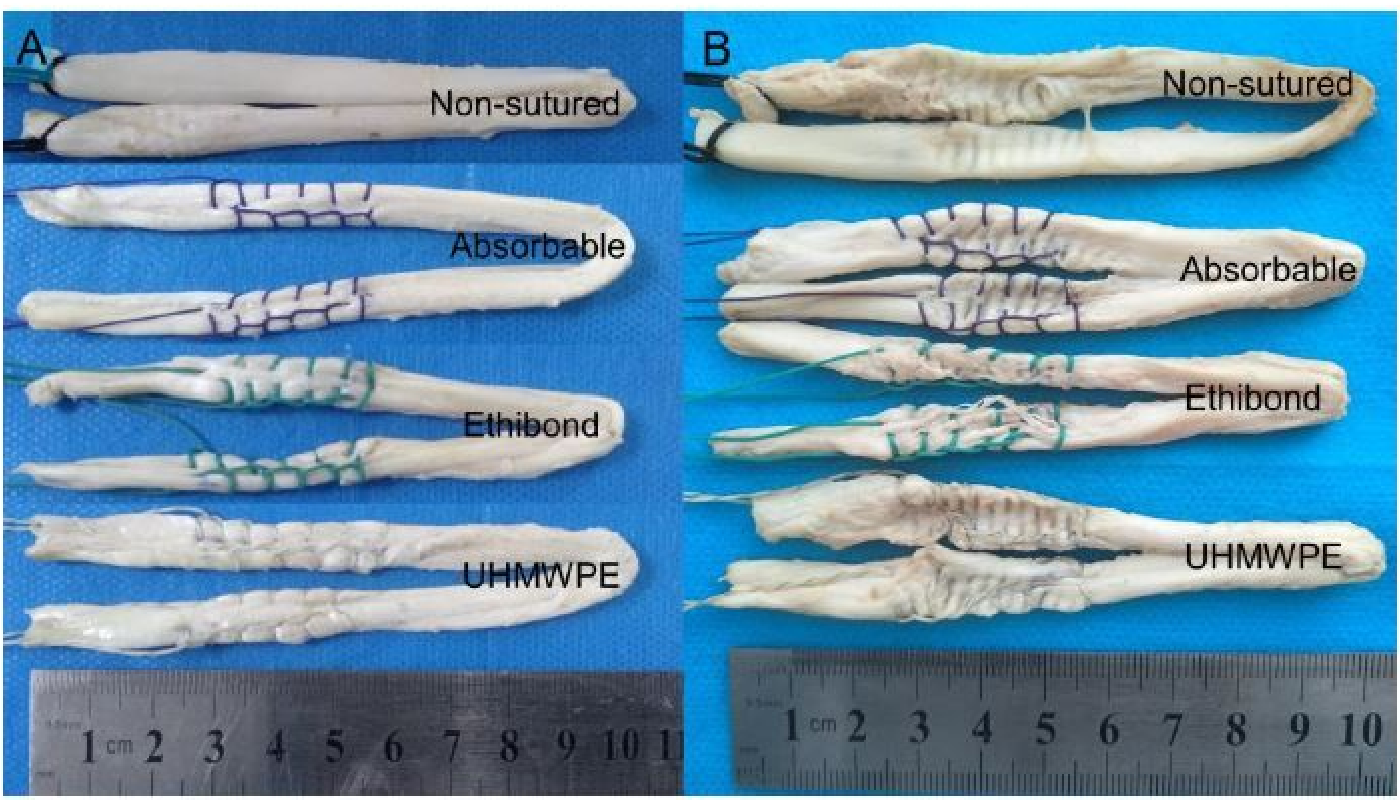

Figure 4

The comparison of grafts sutured using different sutures before and after one single insertion of a PEEK interference screw: (A). before insertion of a PEEK interference screw; (B). after insertion of a PEEK interference