Loop changes after knee flexion-extension movement in a cadaveric anterior cruciate reconstruction model

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Abstract

Background: Recently, adjustable-loop devices (ALDs) have been widely used, and their reliability has always been the focus of attention. This study compared loop length changes under pull stress caused by flexion and extension of the cadaver knee between ALDs and fixed-loop devices (FLDs) in terms of femoral fixation after anterior cruciate ligament (ACL) reconstruction.

Methods: ACL reconstruction in cadaveric knee joints was performed under arthroscopy with femoral suspension devices and tibial fixation by tying sutures on staples. The knee joint was repeatedly flexed and extended 30 times after fixation. According to the femoral fixation device used (Endobutton or Ultrabutton), the knee joints were divided into two groups: the ALD group (12 specimens) and the FLD group (ten specimens). The length of the loop before and after fixation was measured, and the loop length of the ALD group was re-measured 1 day after reconstruction.

Results: There was no significant difference in the length of the loop between the two groups ($t = 0.579$, $P = 0.569$). One day later, the loop length of the ALDs retracted by 0.29 ± 0.33 (0–1.1) mm, and there was no retraction in three specimens.

Conclusion: There was no significant difference in the loop length under flexion and extension stress after ACL reconstruction between ALDs and FLDs.

Keywords: Adjustable loop; Anterior cruciate ligament; Fixed loop; Reconstruction; Suspensory fixation

Introduction

Femoral suspension fixation has been widely used in anterior cruciate ligament (ACL) reconstruction as a reliable femoral fixation method. Fixed-loop devices (FLDs) are characterized by reliable fixation strength represented by an Endobutton, with a higher failure load than interference screws.[1] However, FLDs have disadvantages, for example, no loop length of FLD is less than 15 mm now, so it will be difficult to use FLD when the total length of the bone tunnel is shorter than 30 mm in the clinic. In addition, to facilitate the flipping of the plate, the length of the thick bone tunnel is greater than the length of the graft, which is prone to a bungee effect and affects tendon-to-bone healing.[2] Adjustable-ligament devices (ALDs) have an adjustable one-way lock mechanism, relying on multiple points of friction and resistance once tension exceeds a certain threshold. ALDs can rigidly maintain length while a load larger than the threshold is applied.[3] At the same time, the length of the thick bone canal is fixed at the appropriate length,[3] which greatly reduces the attic height of the femoral tunnel and can improve graft and bone incorporation. However, ALDs are engineered to maintain one-way tensioning, and their fixation reliability is questioned because the loop may loosen and lengthen after cyclic loading.

Because graft tension is mainly maintained by the fixation device in the early post-operative period and because early rehabilitation programs after ACL reconstruction consist of passive flexion activity, the purpose of this study was to compare loop lengthening between FLDs and ALDs by cyclic extension and flexion after ACL reconstruction with FLDs and ALDs. Our hypothesis was that there would be no difference in loop lengthening between ALDs and FLDs.

Methods

Bone tunnel drilling

This research was approved by the Department of Human Anatomy and Embryology, Peking University Health Science Center. The graft was replaced by tape, and the diameter was close to 6 mm after double folding. In a cadaveric knee joint, the ACL was removed under

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arthroscopy. The femur bone tunnel was located in the center of the direct insertion of the ACL, and the middle point of the bone tunnel was just under the lateral intercondylar ridge of the lateral femoral condyle when knee flexed to 90°. The femoral bone tunnel was drilled with a 6 mm hollow drill bit, and the length of the measured bone tunnel was 40 mm. The tibial jig was set at 55°, and the tibial bone tunnel was located in the middle point of the anteromedial part of the ACL native footprint.

Grouping and testing

According to the femoral fixation device used (Endobutton or Ultrabutton, Smith & Nephrew Endoscopy, Andover, MA, USA), the knee joints were divided into two groups: the FLD and ALD groups. In the FLD group, ten Endobuttons with loop lengths ranging from 15 to 30 mm were used to fix grafts in the femoral tunnel. The intact loop length was measured with calipers [Figure 1], and then the fixation device and the graft were passed through the tibial tunnel to the femur under arthroscopic control. The femoral end was fixed by flipping the button plate. The tibial end was tensioned by one stretcher for 15 s under 80 N tension, and then the graft was tied to the tibial nail [Figure 2] under full extension. After the knee joint was moved from extension to 120° flexion 30 times, the graft and Endobutton were removed, and the loop length was measured again. In the ALD group, 12 Ultrabuttons were selected to fix grafts in the femoral tunnel. First, the loop was shortened to a certain distance before fixation, and then the loop length was measured as described above as the

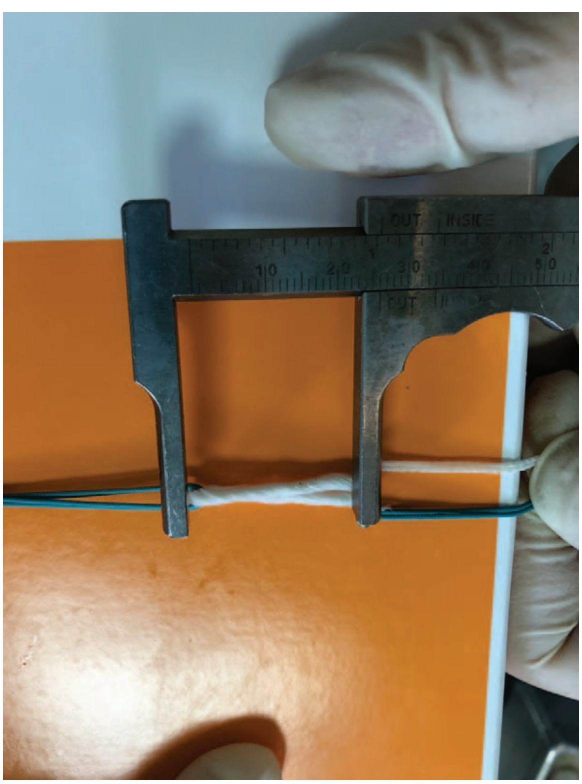

Figure 1: The distance from the steel plate to the end of the loop was measured as loop length.

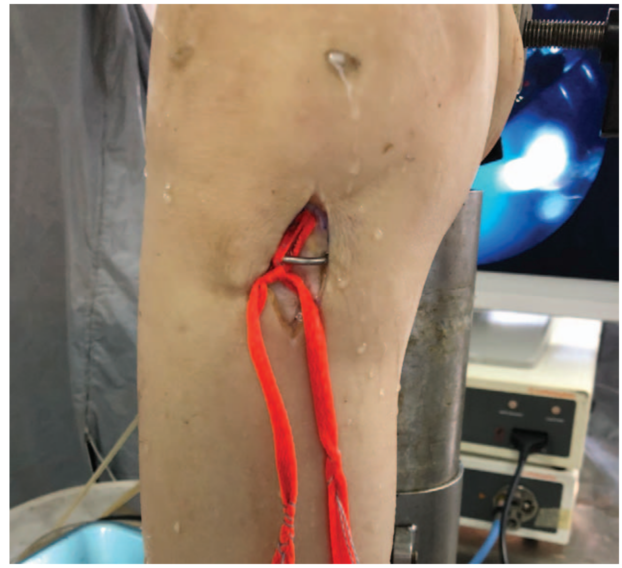

Figure 2: The graft was tied to the tibial nail.

Table 1: The loop length of FLDs before and after fixation (mm).

No.	Loop length before fixation	Loop length after fixation
1	17.5	19.5
2	19.8	21.3
3	21.5	22.8
4	21.5	22.7
5	25.5	28.0
6	26.5	29.5
7	27.0	28.5
8	27.5	28.1
9	31.0	33.9
10	31.5	33.3

FLDs: Fixed-loop devices.

primary length. After fixation and repeated extension and flexion as described above, the loop length was measured again.

One day after removing the fixation device, the loop length in the ALD group was measured again.

Statistical analysis

The results are expressed as the mean ± standard deviation. The measurement results were tested by independent *t*-tests, and the data were analyzed by SPSS software, version 21.0 (IBM, Chicago, IL, USA).

Results

The loop lengths of the FLDs before and after fixation are shown in Table 1, and the loop lengths of the ALDs before and after fixation are shown in Table 2. The loop length variation of Endobutton was 1.83 ± 0.77 (0.6–2.9) mm, while that of Ultrabutton was 1.64 ± 0.75 (0.5–3.0) mm ($t = 0.579$, $P = 0.569$). There was no significant difference in length variation between the two groups

Table 2: The loop length of ALDs before and after fixation (mm).

No.	Loop length before fixation	Loop length after fixation
1	9.5	12.5
2	15.1	16.0
3	14.9	17.1
4	19.0	20.5
5	23.1	24.6
6	23.9	26.0
7	26.0	28.3
8	27.1	29.1
9	31.9	33.5
10	33.5	34.0
11	32.5	34.1
12	35.0	35.5

ALDs: Adjustable-loop devices.

Table 3: Loop length of ALDs 1 day after fixation (mm).

No.	Loop length after fixation	Loop length 1 day after fixation
1	12.5	12.5
2	16.0	15.9
3	17.1	16.8
4	20.5	19.9
5	24.6	23.5
6	26.0	25.7
7	28.3	28.3
8	29.1	29.0
9	33.5	33.0
10	34.0	33.6
11	34.1	34.0
12	35.5	35.5

ALDs: Adjustable-loop devices.

The loop lengths of the ALDs 1 day after fixation are shown in Table 3. The average retraction distance was 0.29 ± 0.33 (0–1.1) mm.

Discussion

One of the important procedures during ACL reconstruction is reliable fixation of the graft.[1] Although FLDs are fixed firmly to prevent grafts from loosening, the attic height of the femoral tunnel is usually 6 mm (half the length of the plate) longer the graft length inside the femoral tunnel to ensure the button plate flipping, which will not only affect bone preservation, but graft stability and tendon-to-bone healing also.[4,5] ALDs do not need to reserve additional attic height to flip the button plate, so the length of grafts and the length of bone tunnels are well matched, avoiding the disadvantage described above.[4,5,6] ALDs also have the capability of re-tensioning grafts after initial fixation. In addition, ALDs are more suitable than FLDs in the case of a short bone tunnel because the shortest loop length of an FLD is 1.5 cm, which is not convenient in a case where the total length of the femoral bone tunnel is less than 3 cm. However, after ALDs are fixed, they may be prolonged due to suture sliding.[4,5,6]

In the comparative biomechanical study of ALDs and FLDs,[3,4-8] most authors believe that the elongation of ALDs is greater than that of FLDs, while some authors believe that the difference in elongation between the two fixed devices is not obvious.[9] Nye *et al*[3] found that the displacement was significantly improved, and there was no significant difference between ALDs and FLDs after re-tensioning the ALDs. Barrow *et al*[4] knotted the sutures of ALDs and found that there was no significant difference in displacement between ALDs and FLDs. Although it has been reported that different suspension femoral devices (including FLDs and ALDs) have different failure loads, all of which are more than 800 N, and the proportion of suture failure in ALDs (69.4% or more) is larger than that in FLDs (60.3%),[10] the minimum failure load (TightRope) is sufficient for ACL reconstruction, and the failure load of ALDs with suture knotting is similar to that of FLDs.[4] Tendon-to-bone healing takes 6 to 12 weeks for autografts and 6 months for allografts.[4,6,11] In the early stage (within 6 weeks) after ACL reconstruction, the graft strength decreased significantly because of graft necrosis. At this time, the rehabilitation program mainly consisted of passive knee flexion and extension, and the stress of the graft was relatively small. After that, due to tendon-to-bone healing, the influence of the fixation device on the graft decreased gradually. Therefore, the failure load of the fixation devices was not a critical factor in the early stage after ACL reconstruction, so 30 cycles of passive knee flexion and extension were performed in this study to imitate the early post-operative load of fixation devices.

This study was different from previous biomechanical studies on loop length changes of ALDs. They used porcine knee joint specimens or only the fixation device itself, without using cadaveric knee, which did not conform to the biomechanical characteristics of the human body. In this study, human cadaveric knee joint specimens were used to test the elongation of the femoral fixation devices following passive knee flexion and extension just as during operation. To prevent the influence of bone tunnel position on the results, we used the same bone tunnel of the same knee joint specimen. We performed a standard operation to ensure the standardization of the load, including fixation at full extension and using a fixed pull strength. In this study, there was no significant difference in the elongation of ALDs or FLDs. During the test, the mean loop length was less than 3 mm, which met the clinical requirements and was consistent with the results of some clinical researches.[12,13]

Nye *et al*[3] observed that suture slippage resulted in elongation of ALDs, and Petre *et al*[8] suggested that an adjustable loop should be re-tensioned after knee joint movement. However, in this study, it was also found that the FLDs had elongation, and the creepage of the fixation device itself under pull stress was also the reason for the elongation of the loop.

Whether the elongation of ALDs is caused by the creepage of the device itself or by suture slippage cannot be clearly distinguished. In this study, through measurement of the FLDs, it was also found that the FLDs also had prolongation, and the prolongation of the FLDs was due to creepage. The loop length of the ALDs was measured again one day after fixation to observe whether there was retraction of the loop length. The results showed that most of the loops had slight retraction, indicating that creepage of the loop existed, but the retraction length changed little, no more than 0.5 mm, indicating limited tissue shrinkage will be caused by loop creepage. There were also three cases without any loop retraction, which showed that the lengthening was partially caused by suture slippage.

The ALDs with an initial loop length of 12 mm had elongated more than 3 mm. So attention should be paid for cases who need short loops, because the loop of the ALDs may be re-tensioned after repeated flexion and extension movements.[4]

There were some limitations in this research. First, more precise electronic markers could be used to make the measurement more accurate. In addition, the number of fixation devices was limited, and the relationship between the initial loop length and the loop lengthening could not be evaluated.

In conclusion, we observed no significant difference in elongation between ALDs and FLDs under passive flexion and extension stress. ALDs should be reliable and effective fixation devices.

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Conflicts of interest

None.

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