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ORIGINAL PAPER

Strength of suture-button fixation versus ligament reconstruction in syndesmotic injury: a biomechanical study

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Abstract

Purpose To compare the biomechanical characteristics of suture-button fixation versus ligament reconstruction using semitendinosus tendon autograft in treatment of syndesmotic injury in cadaver biomechanical study.

Methods Eight matched pairs of human cadaveric lower-extremities were measured intact, then following simulated syndesmosis injury by cutting the anterior tibiofibular ligament (AITFL), the distal 15 cm of the interosseous membrane (IO), and the deltoid ligament. Thereafter, the syndesmotic injury was treated by suture-button fixation or ligament reconstruction. The semitendinosus tendon was harvested as a graft. Biomechanical testing was performed after the surgical fixation. The foot underwent rotation from neutral position to an external rotation at a rate of 5°/s to 12.5 Nm. The three-dimensional syndesmotic diastasis readings, final rotation torque, and rotational angle were recorded.

Results No difference was found in fibular displacements between two groups. Moreover, no significant difference was found in final rotation torque (11.95 ± 1.03 VS 11.66 ± 1.18 Nm, $P = 0.62$) and rotation angle (43.61° ± 14.77° VS 40.93° ± 10.94°, $P = 0.56$) in the suture-button group and ligament reconstruction group.

Conclusion The stability of the suture-button fixation was equivalent to ligament reconstruction using semitendinosus tendon autograft in treatment of syndesmotic injury as determined with biomechanical testing. However, this study does not prove that one is advantageous over the other.

Keywords Syndesmosis · Instability · Suture button · Ligament reconstruction · Biomechanics

Introduction

Syndesmosis injury has been reported as accounting for 20 to 40% of all ankle injuries among young athletes [1–3]. As an increase in knowledge and understanding of clinical diagnosis, biomechanics, and the cause, the incidence of syndesmotic injuries has been increasing recently [4].

Chronic syndesmotic injuries are defined as injuries that present with symptoms exceeding six months after the initial trauma [5]. Restoration of the stability of the tibiofibular syndesmosis is important to restore normal ankle stability not only enables the patients to return to their pre-injury daily and athletic activities [6], but also could prevent the ankle re-injury and early development of osteoarthritis. Many symptomatic chronic syndesmotic injuries are not effective to non-surgical treatment and often need surgical intervention [7]. Surgical treatment methods include arthroscopic debridement [8, 9], screw fixation [8, 10], suture-button fixation [11, 12], anatomical reconstruction of syndesmotic ligaments [13–16], and distal tibiofibular arthrodesis [10, 17, 18]. Despite the many treatments utilized, there is still no gold standard for the management of chronic syndesmotic injuries [19]. The treatment of these injuries is variable and depends on the length and severity of the symptoms [7, 20].

The suture button is a relatively new surgical implant based on a suture-button design [21]. This product could provide semirigid dynamic stabilization of the ankle mortise, which is believed to resist diastases of the tibiofibular syndesmosis while allowing for early weight-bearing [12]. Moreover, no need to remove the fixation is also an advantage of this

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fixation. Many previous biomechanical studies indicated that the suture-button fixation was equal to screw fixation during an external rotation force [22–24]. However, no biomechanical study compared the suture-button fixation with anatomical ligament reconstruction. The purpose of this study was to compare the biomechanical characteristics of these two surgical techniques. It was hypothesized that there is no difference in the three-dimensional syndesmotic diastasis, torque, and rotational angle biomechanical cadaver testing between suture-button fixation and anatomical ligament reconstruction.

Methods

Specimens and graft preparation

Eight pairs of 16 fresh-frozen human through-knee lower-extremity cadaver specimens (16 legs in total) with intact knee regions were obtained and approved for use by the Body Donation Center of the authors' University. The mean age of the patients at death was 58.5 years (range, 49–69 years), with an equal ratio of male to female cadaveric ankles obtained. The legs were examined visually and radiographically to rule out major ankle and knee pathology. The specimens were fresh frozen and stored at −20 °C. Prior to the surgery and biomechanical testing, the cadaveric legs were thawed at 5 °C for 24 hours. The moisture of the specimens was maintained with saline spray during preparation and testing phases.

The ankle joint and syndesmosis were stripped of the skin and subcutaneous tissue to expose the syndesmosis ligaments, deltoid ligament, and interosseous membrane.

For graft preparation, a free semitendinosus graft was harvested using a standard technique and trimmed to 150 mm in length and 4.0 mm in diameter as the graft tendon. Both of the two ends of the free graft were armed tightly by a no. 2 nonabsorbable Ethibond suture (Ethicon Inc., Somerville, NJ, USA) with a modified Prusik knot [25]. Before the biomechanical testing, the graft was tensioned under 10 N for ten minutes.

The specimen for suture-button fixation was chosen at random, and the paired contralateral ankle was used for anatomical ligament reconstruction. All surgical procedures were performed by a single senior surgeon.

Each specimen was tested in three stages (stage 1, specimens intact; stage 2, specimens with section; stage 3, specimens with fixation). For stage 1, each specimen with all ligaments intact was tested, and this stage was established as a baseline model for anatomic motion of the syndesmosis. For stage 2, a simulated syndesmosis injury model was created by sectioning the anterior tibiofibular ligament (AITFL), the distal 15 cm of the interosseous membrane (IO), and the deltoid ligament [4]. For stage 3, the suture-button fixation or anatomical ligament reconstruction was performed based on the grouping.

Surgical techniques

The syndesmosis was carefully reduced using a reduction clamp under image intensification.

In the suture-button technique, a 3.5-mm hole was made from the lateral cortex of the fibula to the medial cortex of the tibia, directed anteromedially at 30° to the frontal plane. The hole was made 2 cm proximal to the joint line. The suture-button construct was then passed from the lateral fibular cortex to medial cortex of the tibia with a passing suture. After that, the button at the medial cortex of the tibia was pulled back and flipped to anchor onto the medial tibia cortex. The FiberWire construct was then hand-tied to maintain the reduction position using a locking stitch followed by five half-hitch throws (Fig.1) [4, 26].

For the anatomical ligament reconstruction technique, a guide wire was drilled from the lateral cortex of the fibula directed anteromedially at 30° to the frontal plane approximately 2 cm proximal to the ankle joint. The wire was then over-drilled to the same diameter as the graft through all the cortices (tunnel 1). A second wire was placed anterior to the fibula through the tibia alone just above the level of the first tunnel 1 cm and again over drilled to 7.0 mm (tunnel 2). The graft was then threaded through tunnel 1 and pulled back through tunnel 2 and tensioned before being secured with 7.0 mm in diameter, 15-mm long interference screw (DePuy Mitek, Inc., Raynham, MA, USA) through the tibial tunnel. Therefore, the IO and AITFL were reconstructed (Fig. 2) [15].

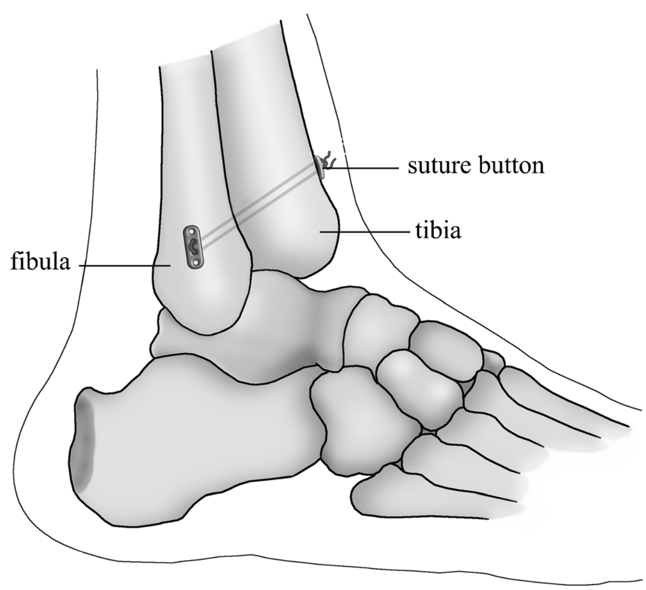

Fig. 1 Illustration of the surgical technique of suture-button fixation

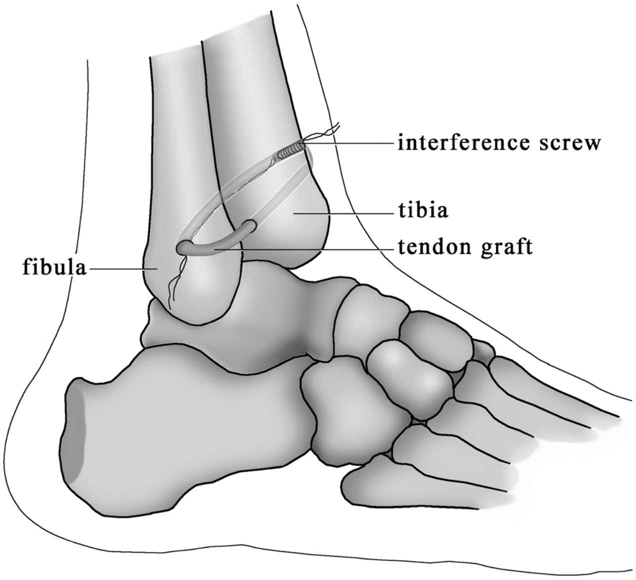

Fig. 2 Illustration of the surgical technique of syndesmotic reconstruction

Biomechanical testing

Four tantalum beads were implanted into the insertions of the AITFL at the fibular and tibia, respectively, to be used as reference markers for the measuring (Fig. 3). For biomechanical testing of the constructs, each foot was fixed onto a custom-designed metal plate with one 5-mm diameter Steinmann pins at the calcaneus bone and a compression plate at the top of the metatarsal bones. The metal plate then was placed on the base of the testing machine (DDL2D Testing System, Changchun Research Institute for Mechanical Science Co. LTD., Changchun, Jilin, China). The knee joint was also fixed in extension with a 5-mm pin [4]. The femur shaft was fixed at the proximal end of the material testing machine with dental cement (Shanghai New Century Dental Materials Co., Shanghai, China).

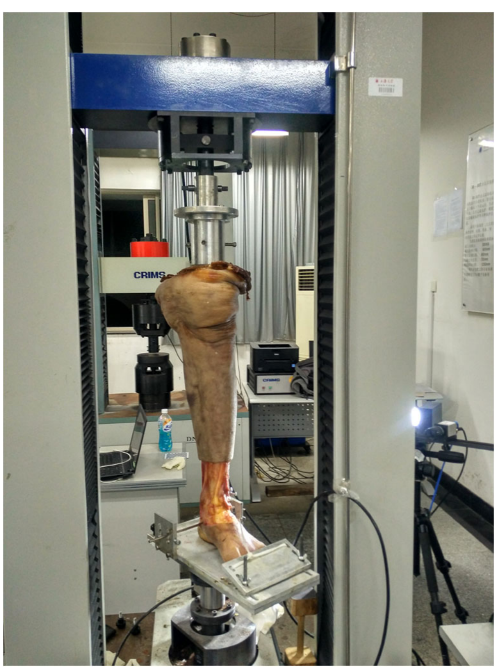

Fig. 3 The lower lower-extremity was fixed on the biomechanical machine

Each specimen was loaded under an axial load of 700 N, and the foot underwent rotation from neutral position to an external rotation at a rate of 5°/second to 5 Nm of torque for ten rotational cycles as pretension [24]. After the ten rotational cycles, the biomechanical testing was performed. In stages 1 and 2, the foot underwent rotation from neutral position to an external rotation at a rate of 5°/second to 5 Nm of torque. In stage 3, the foot underwent rotation from neutral position to an external rotation at a rate of 5°/second to 12.5 Nm or the failure of the fixation. The mode of failure was recorded in detail, including fracture, hardware breakage, or tendon rupture. During the test, the reflective markers' displacements were collected using a three-dimensional digital image correlation system (3D-DIC) (VLG-20M CCD, Baumer Ltd., Frauenfeld, Switzerland) every one second [27]. The 3D-DIC is an advanced optical technology to capture and analyze the three-dimensional displacement of the subjects. The measurement accuracy is 0.01 mm [28]. In the current study, the relative three-dimensional motions occurring between the distal fibula and tibia during physiological ankle joint motion were measured. The torque, rotational angle, and mode of failure were also recorded. During testing, the tissue was kept moist with saline and room temperature was maintained at a constant 22 °C.

Statistical analysis

A priori power analysis was used to calculate the sample sizes. The minimum clinically important difference was selected to be 2.5 mm, and a standard deviation of 1.5 mm was assumed in each group. For a power of 0.8 and a significance level of 0.05, five specimens in each group were needed [22]. The paired t test was used. Data were shown as the mean ± standard deviation (SD). Differences were considered to be statistically significant for P values of < 0.05. All statistical analyses were conducted using SPSS 19.0 (IBM Corporation, Armonk, NY, USA).

Results

Syndesmotic diastasis

In the suture-button fixation group, the average displacements of fibular were 1.50 ± 0.78 and 5.76 ± 3.32 mm posteriorly, 1.72 ± 2.04 and 2.81 ± 2.22 mm laterally, and 0.21 ± 0.08 and 0.48 ± 0.33 mm superiorly, when the foot was externally rotated under 5 and 12.5 Nm of torque, respectively. In the ligament reconstruction group, the average displacements of fibular were 1.32 ± 0.60 and 4.37 ± 2.48 mm posteriorly, 1.62 ± 1.34 and 3.52 ± 2.97 mm laterally, and 0.17 ± 0.07 and 0.33 ± 0.21 mm superiorly when the foot was externally rotated under 5 and 12.5 Nm of torque, respectively. No difference was found in fibular displacements between the two groups (Table 1).

Mode of failure

Two of eight specimens in the suture-button group were failure (the final rotation torque was 10.06 and 10.51 Nm, respectively) whereas three of eight specimens in the ligament reconstruction group were failure (the final rotation torque was 10.02, 10.03, and 10.71 Nm, respectively) during the biomechanical tests. All of them were fractures of fibula. None of the failures in both groups were hardware breakage.

Final rotation torque and rotation angle evaluation

No significant difference was found in final rotation torque (11.95 ± 1.03 VS 11.66 ± 1.18 Nm, n.s.) and rotation angle (43.61° ± 14.77° VS 40.93° ± 10.94°, n.s.) in the suture-button group and ligament reconstruction group.

Discussion

The most important found in this study was that there is no difference in the three-dimensional syndesmotic diastasis, torque, and rotational angle biomechanical cadaver testing between suture-button fixation and anatomical ligament reconstruction. The consequences of chronic syndesmotic injury include persistent instability and abnormal compression in the ankle. Previous biomechanical studies indicate that a lateral shift of the talus of 1.5–2 mm can lead to an increase in pressure of up to 50% in the lateral joint compartment of the ankle [29, 30]. In Weening and Bhandari's research [31], the authors found that syndesmotic reduction was the sole variable that was significantly associated with the variability observed in a validated outcome instrument and an ankle-specific questionnaire used to assess function post-operatively. Therefore, it is very important to restore the original geometry of intact syndesmosis.

Numerous surgical techniques exist for the operative treatment of chronic instability of the syndesmosis. Most of these techniques combine restoration of the length and rotation of the fibula with debridement of interposed tissue from the tibiofibular articulation to reposition the lateral malleolus anatomically within the fibular notch. Repair or reconstruction of the tibiofibular ligament reestablishes the syndesmosis and achieves dynamic stability of this osseous relationship. In these techniques, screw fixation, suture-button fixation, and ligament reconstruction are three most popular types of surgical treatments. Problems with screw fixation have been reported and included the following: late syndesmotic widening after screw removal, screw loosening, screw breakage, the need for a second operation to remove the screw, and morbidity associated with prolonged immobilization [32]. Moreover, once chronic tibiofibular syndesmotic injury has occurred, the fibrous scar tissue will form at the tibiofibular syndesmosis, which will affect its stability and strength. Therefore, tibiofibular syndesmotic diastasis will inevitably recur once the screw has been withdrawn [33]. The more recent development is the suture button (flexible implant) with the potential advantage of preserving physiologic motion in the tibiofibular joint. Other advantages of suture button include allowing for a smaller incision, less surgical dissection, improved surgical efficiency, and being strong enough to maintain reduction in the syndesmosis [34]. Previous biomechanical studies found that the suture button demonstrated good resistance to axial

Table 1 Syndesmotic diastasis during the biomechanical test

Condition	External rotated torque	Fibular movement	Suture-button group	Ligament reconstruction group	*P* value
Intact	5 Nm	Posterior	2.03 ± 2.71	1.95 ± 1.26	n.s.
		Lateral	1.22 ± 0.91	1.51 ± 0.80	n.s.
		Superior	0.28 ± 0.21	0.14 ± 0.12	n.s.
Sectioned	5 Nm	Posterior	3.30 ± 2.76	2.79 ± 1.20	n.s.
		Lateral	2.82 ± 3.18	3.05 ± 0.92	n.s.
		Superior	0.76 ± 1.23	0.17 ± 0.15	n.s.
Post-operation	5 Nm	Posterior	1.50 ± 0.78	1.32 ± 0.60	n.s.
		Lateral	1.72 ± 2.04	1.62 ± 1.34	n.s.
		Superior	0.21 ± 0.08	0.17 ± 0.07	n.s.
	12.5 Nm	Posterior	5.76 ± 3.32	4.37 ± 2.48	n.s.
		Lateral	2.81 ± 2.22	3.52 ± 2.97	n.s.
		Superior	0.48 ± 0.33	0.33 ± 0.21	n.s.

Results are given mean ± standard deviation, mm and rotational loads [22–24]. Moreover, suture-button fixation of the syndesmosis results in less post-fixation displacement compared with screw fixation [35]. In a clinical research, Naqv et al. [21] found that fixation with suture button provided a more accurate method of syndesmotic stabilization compared with screw fixation.

Different ligament reconstruction techniques were introduced in previous clinical studies [6, 14, 15, 20], and all of these techniques achieved excellent or good clinical results. However, till now, there is no biomechanical study to compare the suture-button fixation with anatomical ligament reconstruction in syndesmotic injury. In the current research, a relative easy reconstruction technique was introduced, which was similar to Morris's technique [15]. Moreover, the authors' biomechanical research indicated that there is no significant difference in the three-dimensional syndesmotic diastasis, final rotation torque, and rotational angle between suture-button fixation and ligament reconstruction group. We believed that both techniques demonstrated excellent biomechanical results and could be safely used in treatment chronic syndesmotic injury.

In a biomechanical research, Teramoto et al. [4] found that the suture-button fixed at the direction of parallel to the sagittal plane at the ankle joint level could provide physiologic stability of the syndesmosis in the condition with multidirectional forces. They suggested that much of the fibular motion after syndesmosis sectioning was in the sagittal plane, and this motion might be difficult to control with a suture construct tensioned only in the frontal plane. However, in their study, they admitted that there are some surgical difficulties in this technique, because peroneus tendons and superficial peroneal nerve are in the way of drilling the holes and passing the button. In the current study, the authors found that the fibular motion was both in the sagittal and frontal planes after syndesmosis sectioning. Moreover, previous anatomic study indicated that the direction of AITFL and posterior tibiofibular ligament (PITFL) in the sagittal plane were 65° and 85°, respectively [36]. Therefore, the suture-button fixation direction was 30° to the frontal plane in the current study, which was similar to most of the previous biomechanical and clinical studies [11, 12, 22, 26, 37].

In previous biomechanical studies [4, 38], no significant difference in syndesmosis diastases was found between single and double suture-button fixation groups. Therefore, single suture-button fixation was used in the current study.

Previous studies indicated that the external foot torque test produced the highest mean distal fibular force when external foot torque was applied and loaded with applied axial weight bearing force [39]. It would be reasonable to expect that external foot torque would cause the talus to rotate out of the ankle mortise, thereby widening the mortise and causing the fibula to displace laterally [39]. Therefore, in the current study, external foot torque and axial load force were applied together to simulate the nature syndesmotic injury. Forsythe et al. [26] found that many of the ankles might fail if the rotational load is beyond 12.5 Nm. Therefore, in the current study, the external rotation torque is up to 12.5 Nm.

A biomechanical study found the ultimate failure loads were significantly higher for the double polyester/flip button repair (927 N) compared to different kinds of tendon repair techniques (maximum 640 N) in anatomical coracoclavicular ligament repairs. The authors indicated that flip button repair could provide adequate structural properties compared to a tendon repair [40].

The graft used in the current study was single semitendinosus tendon with the diameter of 4.0 mm. In a previous biomechanical research, single semitendinosus tendon had mean maximum failure load of 1060 N, with the mean diameter of 3.7 mm [41]. The failure load was higher than the strength of anterior tibiofibular (499 N) and posterior tibiofibular (708 N) [42]. Thereafter, we believed that single semitendinosus tendon with the diameter of 4.0 mm could be safely used in syndesmotic reconstruction.

In a systematic review article, the surgical complications related to harvesting of the hamstring tendon occurred in 8.3% of cases. The main complication was sensory deficit because of damage to the infrapatellar branches of the saphenous nerve. This risk can be reduced by using a horizontal or oblique incision [43].

Both the suture-button fixation and ligament reconstruction were used in treatment of chronic syndesmotic injury in daily clinical practice [11–16]. In the current study, no difference in stability was found between these two techniques during the biomechanical testing. Considering the potential complications related to harvesting of the autograft and the relative smaller incision and easy to operate for the suture-button fixation technique, we believed that the suture-button fixation may be a better choice in treatment of chronic syndesmotic injury.

Limitations

There are some limitations to our study. One limitation was that the methodology used in this study only simulated an acute injury instead of a chronic syndesmotic injury. As we know, it is very difficult to duplicate the chronic syndesmotic injury in a biomechanical study. The study simply looked at the pure strength of fixation between a suture-button construction and a tendon graft construction in a cadaveric time zero model. The second limitation in this study was that it was difficult to simulate the normal syndesmosis movement during daily activities in biomechanical study. A more appropriate physiologic test condition could be cyclic loading. This could lead to destabilization of the fixation by several mechanisms caused by fatigue or distortion of the fixation.

Therefore, additional evaluation in living subjects is required to support the conclusions of current study. Finally, the third limitation was the specimens used in biomechanical testing should have a similar age to those of patients who commonly require syndesmosis reconstruction. Studies indicate that the average age for chronic syndesmosis ligament stabilization ranges from 28 to 40 years [9, 13–16]. However, most of the donated specimens were of an old age, and young cadaveric specimens were not available for the biomechanical testing. Therefore, to compensate for this, we used matched pairs to test the two techniques.

Conclusion

The stability of the suture-button fixation was equivalent to ligament reconstruction using semitendinosus tendon autograft in treatment of syndesmotic injury as determined with biomechanical testing. However, this study does not prove that one is advantageous over the other.

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Compliance with ethical standards

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. For this type of study, formal consent is not required.

Conflict of interest The authors declare that they have no conflict of interest.

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