Int J Clin Exp Med 2020;13(2):1084-1091
www.ijcem.com /ISSN:1940-5901/IJCEM0103643

Original Article

The clinical effects of different repair methods on the biomechanical stability of ankle ligament injuries

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Received October 17, 2019; Accepted November 20, 2019; Epub February 15, 2020; Published February 28, 2020

Abstract: Objective: To explore the effects of different repair methods on the biomechanical stability of patients with ankle ligament injuries. Methods: Normal ankle specimens from 24 adult cadavers were randomly divided into groups A, B, C, D, E, and F, with 4 in each group. Group A was not given any treatment. Group B was established as a distal tibiofibular syndesmosis ligament fracture model, while group C was established as a medial and lateral ligaments and distal tibiofibular syndesmosis ligament fracture model. The models in groups D, E, and F were all established in the same way as group C, but group D had repaired medial and lateral ligaments, group E had repaired lateral ligaments and distal tibiofibular syndesmosis ligaments, and group F had repaired medial and lateral ligaments and distal tibiofibular syndesmosis ligaments. A biomechanical tester was applied to analyze the influence of the ligament injuries and repair methods on the stress areas and ankle joint surfaces. Biomechanical data in dorsiflexion 20°, eversion 5°, internal rotation 20°, plantar flexion 30°, external rotation 20°, and in a neutral position were measured respectively. Results: When the ankle joint was in dorsiflexion 20°, eversion 5°, internal rotation 20°, plantar flexion 30°, external rotation 20°, and in a neutral position, group A showed significantly higher stress areas than the groups B and C (both $P<0.05$), and group F showed significantly higher stress areas than groups D and E (both $P<0.05$). The stress force in group A was significantly lower than it was in groups B and C (both $P<0.05$), and the stress force in group F was significantly lower than it was in groups D and E (both $P<0.05$). There were no significant differences between groups A and F ($P>0.05$). Under loading pressures of 100 N, 200 N, 300 N, 400 N, 500 N, and 600 N, the vertical displacement of the tibiotalar joint in group A was significantly lower than it was in groups B and C (both $P<0.05$), and the vertical displacement of the tibiotalar joint in group F was significantly lower than it was in groups D and E (both $P<0.05$). There were no significant differences between groups A and F ($P>0.05$). Conclusion: Any injury of the medial, lateral, or distal tibiofibular syndesmosis ligaments has an effect on ankle joint stability. Also, a syndesmosis ligament injury can aggravate ankle joint instability, resulting in a reduction of joint stress area and an increase in stress. Repairing all the ligaments is the best way to improve the biomechanical stability of the ankle joint when the three ligaments are fractured jointly.

Keywords: Ligament repair, ankle ligament injury, biomechanics of the ankle joint, stability

Introduction

The ankle joint, composed of the distal tibia, the fibula articular surface, and the talus trochlea, is the weight-bearing joint closest to the ground. The ankle mortise formed by the lower tibia and the medial and lateral ankle articular surfaces accommodates talus bodies. The lateral ankle is lower than the medial ankle and is about 1 cm back. The posterior ankle extends downward to restrict the talus to move backward, thus ensuring the stability of the anatomical structure of the ankle joint [1]. Ankle joint stability is the key to ensuring the normal weight-bearing and motor functions of the body. Studies have proven that the adaptability of bone structures is closely related to the distribution of the peripheral ligaments [2]. The ankle mortise is relatively broad at the anterior part and narrow at the posterior part, which is helpful in reducing the backward and lateral movements of the talus. The peripheral ligaments are distributed downward and backward, effectively fixing the talus to prevent any backwards movement. At the same time, the ligaments and bone structures also have the effects of resisting muscle strength and gravity, as well as preventing the abnormal displacement of the crus bone. The ankle ligaments mainly consist of the medial ligament, the lateral ligament, and the distal tibiofibular syndesmosis ligament. Due to the poor coverage of the peripheral ligaments, the joint capsules, and the muscle tissues, ankle sprains can easily occur during exercise, especially lateral ligament injuries, which account for more than 85% of all ankle ligament injuries [3, 4]. Biomechanical research shows that the ankle joint load is closely related to the contact area of the articular surface [5]. When fully loaded under normal static conditions, the articular surface contacting pattern is relatively constant, with a compression force of the ankle joint of about 2 times of the body weight. However, damage to the internal and external ligaments and to the distal tibiofibular syndesmosis ligaments may lead to an unbalanced contact area and an unbalanced stress distribution on the ankle joint surface, resulting in joint fluid flow and biomechanical changes to the ankle joint. Moreover, an increase in the range of physiological activities of the ankle causes a dilation of the ankle mortise, which ultimately leads to bone tissue damage and degenerative lesions. At present, there is still controversy over the ankle joint repair method involving a joint injury of the three ligaments [6]. Some scholars believe that due to the difficulty in repairing the medial ligament, it is feasible to repair only the lateral ligament and the distal tibiofibular syndesmosis ligament. While Boden theory holds that the biological stability of the ankle joint can be restored by repairing the medial and lateral ligaments, some patients need to be operated on again to repair the medial ligament or the distal tibiofibular syndesmosis ligament. Therefore, some scholars have directly performed the combined repair of the three ligaments in this situation. However, there are insufficient studies on the effects of the different repair methods, so clinicians still rely on their own treatment experience in the choice of surgical methods, lacking standard guidance. This study explored the biomechanical changes of the different types of ankle ligament injuries and the effects of the different repair methods in order to understand the biomechanical changes of ankle ligament injuries and to guide the selection of repair methods.

Materials and methods

Experimental materials

Normal lower limb ankle specimens were collected from 24 adult cadavers, including 16 males and 8 females, aged 18-70 years with an average age of (54.3±8.7) years. All specimens were confirmed by X-ray and visual observation to have a normal ankle structure, and free of ligament injury, fracture, infection, and tumor lesions. All specimens were stored in a 10% formaldehyde solution with an average storage time of 25 days (14-40 days), then randomly numbered and sealed in a refrigerator at -20. The study was examined and approved by the Ethics Committee of Affiliated Nanhua Hospital, University of South China.

Experimental instruments: QX-W400 Biomechanical Tester; XIS-7858 X-ray machine; XJC-Y01-20-4M-Y pressure sensor; anatomical apparatus and surgical instruments.

Specimen grouping, preparation and processing

All specimens were randomly divided into groups A, B, C, D, E, and F with 4 cases in each group. There were no significant differences in terms of gender or age among the six groups (all P>0.05), indicating comparability. All the specimens were taken out 24 hours before the experiment and naturally thawed (20-25), and transected at 25 cm above the ankle joint to retain the intact crus, ankle joint, and foot. Group A received no treatment, and the original ligaments of the ankle joints were preserved. In group B, partial ligament fracture models were established by cutting the distal tibiofibular syndesmosis ligament. In group C, total fracture models of the ankle ligaments were established by cutting the medial and lateral ligaments and the distal tibiofibular syndesmosis ligament. Group D received partial repair surgery to repair the medial and lateral ligaments based on the total ligament fracture models. Group E received partial repair surgery to repair the lateral ligament and the distal tibiofibular syndesmosis ligament on the basis of total ligament fracture models. Group F received repair of the medial and lateral ligaments and the distal tibiofibular syndesmosis ligament based on the total ligament fracture models [7].

Stress area and stress detection

Placement of pressure sensitive film: The specimens were taken out of the refrigerator and thawed at room temperature 2 hours before each experiment. The skin was transversely cut through the anterior wall of the ankle joint capsule. The soft tissue attached to the ankle joint was scraped off, then the articular capsule wall was separated to keep the tibiotalar joint in the field of vision. The specimens were fully dried with an electric blower to eliminate the moisture. An electronic pressure sensor was implanted into the ankle joint cavity. The contacting area between the pressure sensor and the tibial-talus articular surface was at the maximum. During the specimen processing, strict attention was paid to avoid damaging the tendons and ligaments around the ankle joint capsule and to ensure the integrity of the upper and lower articular surfaces of the tibiotalar joint [8].

Biomechanical experiments: The biomechanical data of the five ankle joint states (dorsiflexion 20°, eversion 5°, internal rotation 20°, plantar flexion 30°, external rotation 20°, and neutral position) were measured in the six groups using a QX-W400 biomechanical tester. Specimen fixation and state positioning were completed by professional teachers from the Department of Anatomy with special clamps and vises. The distal tibia and fibula were embedded and fixed with bone cement (parallel to the pelma). The crus and pelma were fixed on a biomechanical tester and a rotating horizontal plate. The loading point was determined, and the ankle joint was adjusted to be in its functional position. The structural model, intercept length, loading form, fixing device, and mechanical properties in each group were set as consistently as possible. Simultaneously, the specimens were adjusted to states of dorsiflexion 20°, eversion 5°, internal rotation 20°, plantar flexion 30°, and external rotation 20°, respectively, and the biomechanical data of the ankle joint in each state and in the neutral position were measured. Measurement method: Before the measurement, the specimens in each group were preloaded with 50 N for 3 times at an interval of 1 min, in order to reduce the influence of ankle flexibility, bone tissue relaxation, and creep time effect on the experimental data. Then, the load pressure was initiated in the central vertical direction, and the peak stress of the ankle joint surface was tested using 100 N grade loading to 600 N, and the stress area was measured at the same time. All the steps were repeated 3 times to take the average value. The vertical displacement of the tibiotalar joint under different loading pressures was measured in the neutral position. After each test, the position of the pressure sensitive film was checked. During the test, the specimens were sprayed with isotonic saline to reduce specimen damage and tissue degeneration.

Statistical methods

The data processing was carried out using SPSS 21.0 statistical software. The measurement data were expressed as ($\overline{x}$ ± sd). *t*-tests were used for the comparison between two groups, and an analysis of variance was used for the comparisons between multiple groups. The counting data were expressed as cases/percentage (n, %). An χ^2 test was used for comparisons between the groups, and a z test was used for the comparison between multiple groups. A Scheffe test was utilized for the intragroup multiple comparisons. A value of $P<0.05$ indicated a significant difference.

Results

Comparison of the stress areas on the ankle joint surfaces under different states

When the ankle joint was in dorsiflexion 20°, eversion 5°, internal rotation 20°, plantar flexion 30°, external rotation 20°, and a neutral position, group A showed significantly higher stress areas than groups B and C (both $P<0.05$), and group F showed significantly a higher stress area than groups D and E (both $P<0.05$). And there were no significant differences between groups A and F ($P>0.05$). See **Table 1** and **Figure 1**.

Comparison of the stress force on the ankle joint surface under different states

When the ankle joint was in dorsiflexion 20°, eversion 5°, internal rotation 20°, plantar flexion 30°, external rotation 20°, and in a neutral position, group A showed significantly lower stress force than groups B and C (both $P<0.05$), and group F showed significantly lower stress force than groups D and E (both $P<0.05$). And there were no significant differences between groups A and F ($P>0.05$). See **Table 2** and **Figure 2**.

Comparison of the displacement values of the tibiotalar joint under different stress forces

Under loading pressures of 100 N, 200 N, 300 N, 400 N, 500 N, and 600 N, the vertical dis-

Table 1. Comparison of the stress areas on the ankle joint surface under different states ($\overline{x}$ ± sd, cm^2)

Group (n=4)	Dorsiflexion 20°	Eversion 5°	Internal rotation 20°	Plantar flexion 30°	External rotation 20°	Neutral position
Group A	341.23±25.76	364.95±34.28	272.31±23.96	326.60±30.72	281.46±24.73	410.72±34.29
Group B	285.63±20.57$^{*,\#}$	303.68±25.70$^{*,\#}$	198.46±20.83$^{*,\#}$	267.76±18.35$^{*,\#}$	218.62±22.95$^{*,\#}$	336.85±23.76$^{*,\#}$
Group C	191.68±16.13$^{*,\#}$	249.73±20.36$^{*,\#}$	153.97±18.50$^{*,\#}$	203.81±16.57$^{*,\#}$	170.95±23.84$^{*,\#}$	238.59±15.42$^{*,\#}$
Group D	254.94±33.68$^{*,\#}$	280.47±23.84$^{*,\#}$	184.74±19.65$^{*,\#}$	247.32±18.04$^{*,\#}$	209.62±25.17$^{*,\#}$	317.48±21.05$^{*,\#}$
Group E	279.47±29.86$^{*,\#}$	291.72±21.94$^{*,\#}$	202.45±20.11$^{*,\#}$	253.36±17.29$^{*,\#}$	203.35±19.64$^{*,\#}$	325.41±23.74$^{*,\#}$
Group F	317.76±38.45	342.84±27.45	220.85±17.47	319.56±20.48	263.41±23.49	389.63±23.46
F	11.731	15.826	9.643	17.940	16.248	21.649
P	0.000	0.000	0.000	0.000	0.000	0.000

Note: Compared with group A, $^*P<0.05$; compared with group F, $^\#P<0.05$.

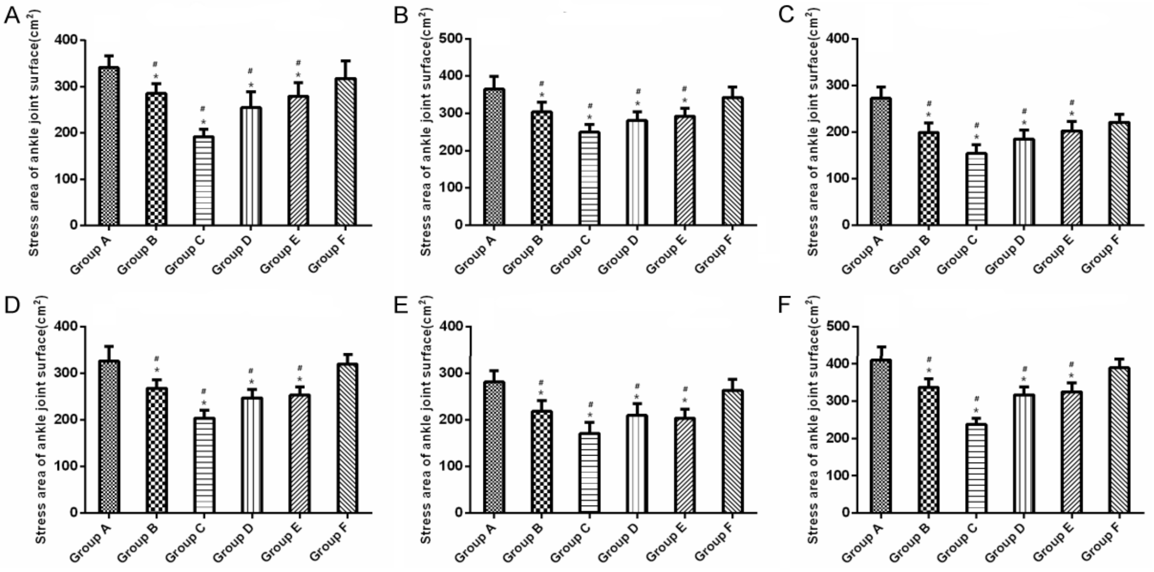

Figure 1. Comparison of the stress areas on the ankle joint surface under different states. Compared with group A, $^*P<0.05$; compared with group F, $^\#P<0.05$. A, dorsiflexion 20°; B, eversion 5°; C, internal rotation 20°; D, plantar flexion 30°; E, external rotation 20°; F, neutral position.

Table 2. Comparison of the stress force on the ankle joint surface under different states ($\overline{x}$ ± sd, kPa)

Group (n=4)	Dorsiflexion 20°	Eversion 5°	Internal rotation 20°	Plantar flexion 30°	External rotation 20°	Neutral position
Group A	3282.43±568.49	2803.76±451.93	3627.60±514.85	3395.65±520.46	3523.94±496.53	2684.85±482.93
Group B	4097.05±304.53$^{*,\#}$	3914.56±398.27$^{*,\#}$	4585.36±394.43$^{*,\#}$	4184.78±561.93$^{*,\#}$	4387.42±413.86$^{*,\#}$	3621.36±534.59$^{*,\#}$
Group C	5033.74±326.67$^{*,\#}$	4520.29±363.82$^{*,\#}$	5116.72±364.97$^{*,\#}$	5223.91±602.58$^{*,\#}$	4742.90±347.86$^{*,\#}$	4362.97±456.02$^{*,\#}$
Group D	4324.30±372.46$^{*,\#}$	4213.44±430.76$^{*,\#}$	4692.83±372.63$^{*,\#}$	4392.47±516.71$^{*,\#}$	4142.83±350.23$^{*,\#}$	3919.54±410.37$^{*,\#}$
Group E	4130.62±377.85$^{*,\#}$	4049.63±420.45$^{*,\#}$	4384.14±359.42$^{*,\#}$	4245.71±436.84$^{*,\#}$	4265.76±363.48$^{*,\#}$	3727.43±393.41$^{*,\#}$
Group F	3595.51±265.94	2914.51±411.23	3813.29±321.35	3516.69±394.65	3839.61±378.50	2922.68±507.42
F	23.588	17.863	13.984	19.627	20.539	15.726
P	0.000	0.000	0.000	0.000	0.000	0.000

Note: Compared with group A, $^*P<0.05$; compared with group F, $^\#P<0.05$.

placement of the tibiotalar joint in group A was significantly lower than it was in groups B and C (both $P<0.05$), and the vertical displacement of the tibiotalar joint in group F was significantly lower than it was in groups D and E (both $P<0.05$). There were no significant differences

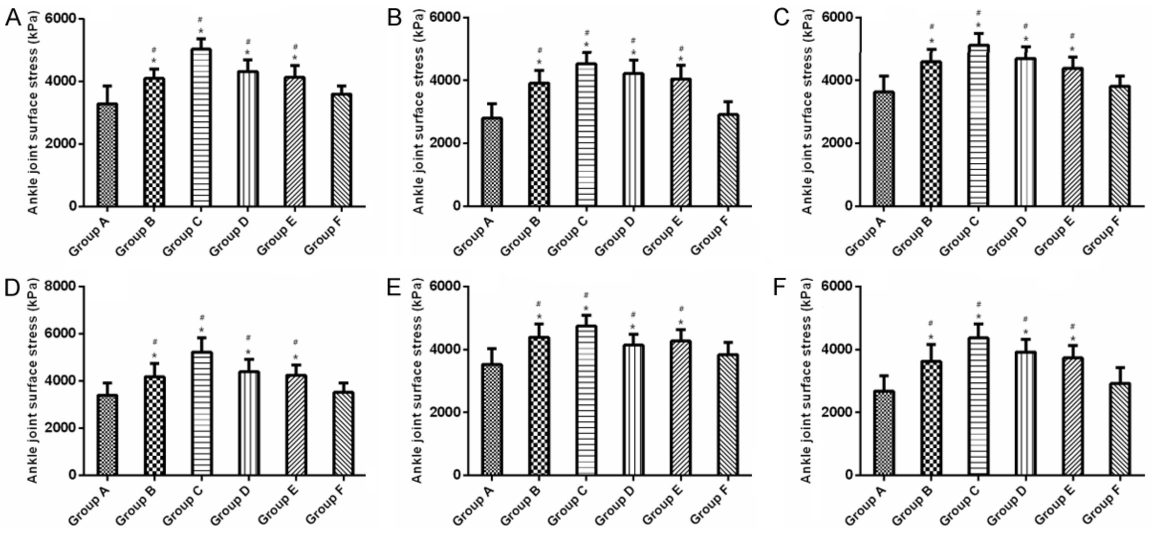

Figure 2. Comparison of the stress force on the ankle joint surface under different states. Compared with group A, $^{*}P<0.05$; compared with group F, $^{\#}P<0.05$. A, dorsiflexion 20°; B, eversion 5°; C, internal rotation 20°; D, plantar flexion 30°; E, external rotation 20°; F, neutral position.

Table 3. Comparison of the displacement values of the tibiotalar joint under different stress forces ($\overline{x}$ ± sd, mm)

Group (n=4)	100 N	200 N	300 N	400 N	500 N	600 N
Group A	3.06±0.15	5.19±0.28	7.20±0.37	8.23±0.54	8.94±0.45	9.91±0.53
Group B	4.93±0.43$^{*,\#}$	6.46±0.50$^{*,\#}$	8.89±0.53$^{*,\#}$	9.76±0.71$^{*,\#}$	10.21±0.57$^{*,\#}$	11.07±0.86$^{*,\#}$
Group C	6.20±0.77$^{*,\#}$	8.33±0.81$^{*,\#}$	10.75±0.87$^{*,\#}$	12.38±1.03$^{*,\#}$	13.49±1.18$^{*,\#}$	14.70±0.98$^{*,\#}$
Group D	5.47±0.47$^{*,\#}$	7.20±0.64$^{*,\#}$	9.92±0.61$^{*,\#}$	10.25±0.68$^{*,\#}$	10.46±1.03$^{*,\#}$	11.49±0.87$^{*,\#}$
Group E	5.34±0.51$^{*,\#}$	7.03±0.56$^{*,\#}$	9.63±0.56$^{*,\#}$	10.57±0.74$^{*,\#}$	10.73±1.20$^{*,\#}$	11.84±0.79$^{*,\#}$
Group F	3.40±0.21	5.63±0.34	7.80±0.43	8.91±0.62	9.54±0.86	10.45±0.63
F	15.284	19.541	16.938	20.181	11.475	14.362
P	0.000	0.000	0.000	0.000	0.000	0.000

Note: Compared with group A, $^{*}P<0.05$; compared with group F, $^{\#}P<0.05$.

between groups A and F (P>0.05). See **Table 3** and **Figure 3**.

Discussion

Ankle bone structure is highly adaptable, and the weight-bearing part of a normal ankle joint presents a relatively constant anatomical morphology and contact area. However, peripheral ligament injuries can reduce its adaptability, increase the inclination angle, offset and displace the talus, and change the anatomical relationship between the tibia and the talus, resulting in a decrease in the contact area on the articular surface and an increase in intra-articular stress. This is also an important mechanism for ankle joint damage and traumatic arthritis [9]. Karakasli et al. showed that, in a neutral position, the weight-bearing of the normal tibiotalar joint is mainly concentrated on the medial and lateral talus trochlear facets, and the contact surface presents two right triangle images with an area of (440±94) cm^{2} [10]. However, ankle ligament injury can cause the talus to clearly shift outward, leading to a significant decrease in the contact area of the tibiotalar joint and a sharp increase in the stress force of the articular surface. A study found that deep medial ligament injury increases the range of motion of the talus in all directions, while cutting the calcaneotibial ligament reduces the contact surface of the tibial joint by 43%, increases the stress force by 30%, and displaces the whole ankle joint by 4 mm [11]. Wenny et al. stated that after an ankle ligament injury, the talus moves outward for 1 cm, and

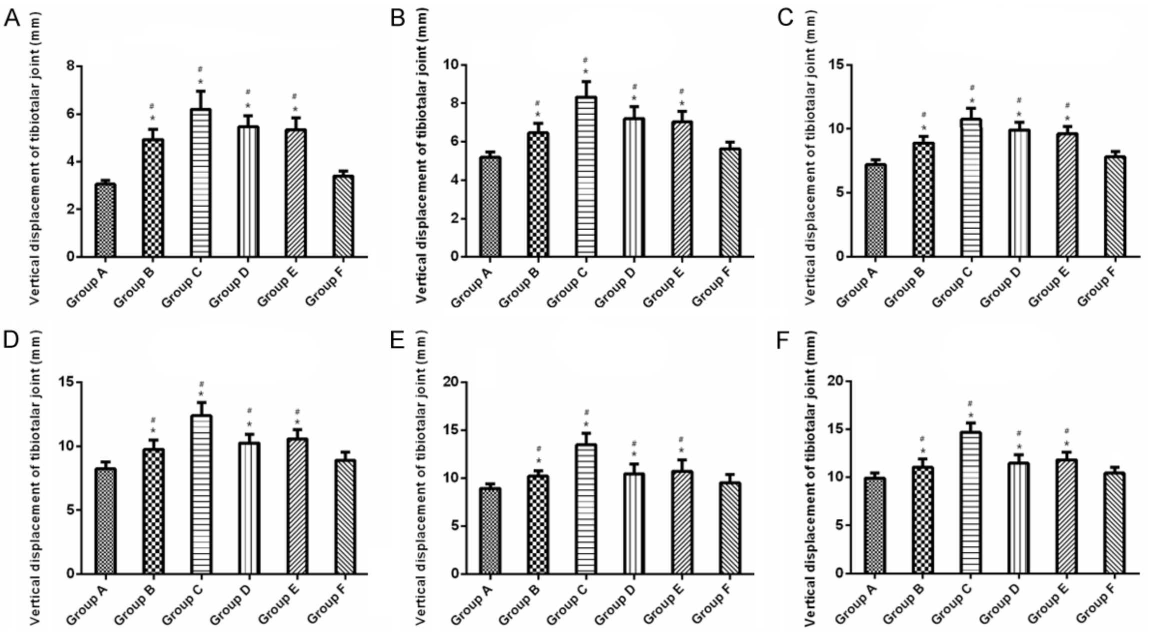

Figure 3. Comparison of the displacement values of the tibiotalar joint under different stress forces. Compared with group A, *P<0.05; compared with group F, #P<0.05. A, 100 N; B, 200 N; C, 300 N; D, 400 N; E, 500 N; F, 600 N.

the stress area on the tibial-talus articular surface is reduced by 42% [12]. However, Ka-Young et al. demonstrated that a fracture of the medial ligament and distal tibiofibular syndesmosis ligament reduces the contact area of the tibial joint by 40% and increases the stress force on the corresponding articular surfaces by 36% [13]. In addition, a study revealed that simply cutting the anterior tibiofibular ligament led to an offset of 2-3 mm in the distal tibiofibular syndesmosis ligament, an offset of 4-5 mm after cutting the joint interosseous ligament, and an offset of 7-9 mm after cutting the anterior, posterior tibiofibular ligaments and the interosseous ligament, which may even lead to ankle dislocation [14]. The lateral ligament is an important ligament for maintaining the stability of the lateral malleolus. A trial on cadaver specimens found that a fracture of the anterior talofibular ligament caused a 3.0-12.1 mm anterior-posterior displacement of the ankle joint and the range of internal rotation would be increased by 10.5° [15], and an anterior subluxation of the talus would be caused when combined with a calcaneofibular ligament fracture. All of these findings proved that the integrity of the ankle ligament is crucial to maintaining the stability of the ankle mortise and talus. In this study, ligament injury models were established on cadaver specimens to analyze the effects of various ligament fractures on the biomechanical stability of the ankle joint. The results showed that the ligament injuries reduced the stability of the ankle joint and affected the stress area and stress force. Moreover, the joint stability was more seriously affected by multiple ligament injuries. This may be due to the fact that the fracture of the distal tibiofibular syndesmosis ligament leads to reduced fibular constraints on the downward movement of the tibia, and the shortening of the lateral malleolus causes increased ankle joint stress. The talus cannot be effectively stabilized after a medial ligament fracture, thus resulting in a decrease of the contact area of the ankle joint surface a corresponding increase of the pressure peak. The relevant conclusions of this study were basically consistent with current reports [16].

A clinical study confirmed that ankle joint injuries involve simultaneous injuries of the medial and lateral ligaments and the distal tibiofibular syndesmosis ligament, which leads to an obvious displacement of the contact position of the ankle joint and increases stress on the joint [17]. Moreover, the injuries also increase the intra-articular pressure and the articular cartilage pressure and affect the normal flow of articular cartilage synovial fluid and nutrition absorption, eventually causing injury, decay, and even necrosis of the articular cartilage.

Meanwhile, the abnormal flow of synovial fluid can affect joint lubrication, reduce the shock absorption effect, and increase the risk of ankle pain, movement restriction, and traumatic arthritis.

There is a consensus on the timely repair and fixation for patients with a joint injury of the 3 ligaments. At present, the clinical repair methods can be divided into three types: First, repair the lateral and distal tibiofibular joint ligaments only. It is generally considered too difficult to repair the medial ligament. Moreover, it has been reported that good ankle joint stability can be maintained without repairing the medial ligaments when joint injuries or ankle ligaments occur. However, Zhao et al. showed that the rates of improper surgical reduction and the postoperative medial clear space in AO/OTA ankle fracture patients with repair of the medial ligaments were significantly lower than they were without repair [18]. Woo et al. suggested that for patients with ankle fractures complicated by medial ligament fractures, repairing the medial ligament significantly improved the Mazur score after the operation and reduced the incidence of joint stiffness and other postoperative complications [19]. Moreover, they believed that the shape and tension of the medial ligament must be repaired in order to effectively prevent the talus from everthing, moving backward and outward, and to improve ankle stability and reduce postoperative complications. Second, repair the medial and lateral ligaments only. Boden's theory holds that a rupture of the distal tibiofibular syndesmosis ligament can only lead to an instability of the ankle abduction, but has little effect on the overall stability. However, the latest biomechanical research indicates that the fracture of the distal tibiofibular syndesmosis ligament weakens the fibular constraints on the downward movement of the tibia [20-23]. And the relative shortening of the lateral malleolus causes an increase in ankle joint stress. Over time, the stress on the articular cartilage cannot be dispersed, resulting in an imbalance of the stress transmission ratio of the tibia and fibula, a deviation of the distal fibula, and an increase in the external rotation of the talus, which eventually leads to ankle instability. Finally, repair the medial and lateral ligaments and the distal tibiofibular syndesmosis ligament. However, there is no comparative study on the effects of the three repair methods on the biomechanical stability of the ankle joint in China. In this study, joint fracture models of three ligaments were established, and the results showed that all the three repair methods improved the stability of the ankle joint. However, the simultaneous repair of three ligaments had a better improvement effect, indicating that medial, lateral, and distal tibiofibular syndesmosis ligaments were the keys to maintaining the stability of the ankle joint. Therefore, in clinical repairs, the simultaneous repair of all the ligaments can achieve the best therapeutic effect.

However, this study only performed a static observation on the biomechanical effects of the ankle joint, so the dynamic effect was not evaluated. Also, taking cadaver ankle specimens as the research objects, the actual healing of ligaments after different surgical procedures was not considered in this study, so the results have great limitations. Therefore, it is necessary to further study the effects of surgical repair with patients as the research objects.

To sum up, any injury of the medial, lateral, and distal tibiofibular syndesmosis ligaments has an effect on ankle joint stability. Syndesmosis ligament injuries aggravate ankle joint instability, contributing to a reduction in the joint stress area and an increase in stress. When the three ligaments are fractured, the failure to repair the medial ligament or the distal tibiofibular ligament can affect the recovery of stability. Therefore, repairing all fractured ligaments is the best way to improve the biomechanical stability of the ankle joint.

Disclosure of conflict of interest

None.

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References

[1] Milner CE and Soames RW. Anatomical variations of the anterior talofibular ligament of the human ankle joint. J Anat 1997; 191: 457-458.

[2] Thompson JY, Byrne C, Williams MA, Keene DJ, Schlussel MM and Lamb SE. Prognostic factors for recovery following acute lateral ankle ligament sprain: a systematic review. BMC Musculoskelet Disord 2017; 18: 421.

[3] Matheny LM, Johnson NS, Liechti DJ and Clanton TO. Activity level and function after lateral ankle ligament repair versus reconstruction. Am J Sports Med 2016; 44: 1301-1308.

[4] De Dea M, L Loizou C, Allen GM, Wilson DJ, Athanasou N, Uchihara Y, Cooke P and Cosker T. Talonavicular ligament: prevalence of injury in ankle sprains, histological analysis and hypothesis of its biomechanical function. Br J Radiol 2017; 90: 20160816.

[5] Evers J, Fischer M, Zderic I, Wahnert D, Richards RG, Gueorguiev B, Raschke MJ and Ochman S. The role of a small posterior malleolar fragment in trimalleolar fractures: a biomechanical study. Bone Joint J 2018; 100-B: 95-100.

[6] Wu K, Lin J, Huang J and Wang Q. Evaluation of transsyndesmotic fixation and primary deltoid ligament repair in ankle fractures with suspected combined deltoid ligament injury. J Foot Ankle Surg 2018; 57: 694-700.

[7] Yasuda T, Shima H, Mori K, Tsujinaka S and Neo M. Simultaneous reconstruction of the medial and lateral collateral ligaments for chronic combined ligament injuries of the ankle. Am J Sports Med 2017; 45: 2052-2060.

[8] Belvedere C, Siegler S, Ensini A, Toy J, Caravaggi P, Namani R, Giannini G, Durante S and Leardini A. Experimental evaluation of a new morphological approximation of the articular surfaces of the ankle joint. J Biomech 2017; 53: 97-104.

[9] Kim YJ and Lee JH. Posterior inferior tibiofibular ligament release to achieve anatomic reduction of posterior malleolar fractures. J Foot Ankle Surg 2018; 57: 86-90.

[10] Karakasli A, Erduran M, Baktiroglu L, Budeyri A, Yildiz DV and Havitcioglu H. The effects of tibiofibularis anterior ligaments on ankle joint biomechanics. Ulus Travma Acil Cerrahi Derg 2015; 21: 90-95.

[11] Mengiardi B, Pinto C and Zanetti M. Medial collateral ligament complex of the ankle: MR imaging anatomy and findings in medial instability. Semin Musculoskelet Radiol 2016; 20: 91-103.

[12] Wenny R, Duscher D, Meytap E, Weninger P and Hirtler L. Dimensions and attachments of the ankle ligaments: evaluation for ligament reconstruction. Anat Sci Int 2015; 90: 161-171.

[13] Chun KY, Choi YS, Lee SH, Kim JS, Young KW, Jeong MS and Kim DJ. Deltoid ligament and tibiofibular syndesmosis injury in chronic lateral ankle instability: magnetic resonance imaging evaluation at 3T and comparison with arthroscopy. Korean J Radiol 2015; 16: 1096-1103.

[14] Birnie MFN, van Schilt KLJ, Sanders FRK, Kloen P and Schepers T. Anterior inferior tibiofibular ligament avulsion fractures in operatively treated ankle fractures: a retrospective analysis. Arch Orthop Trauma Surg 2019; 139: 787-793.

[15] Cao S, Wang C, Ma X, Wang X, Huang J, Zhang C and Wang K. Reliability and validity of different ankle MRI scanning planes for the anterior talofibular ligament injury diagnosis: a cadaveric study. J Orthop Surg Res 2019; 14: 69.

[16] Diallo J, Wagener J, Schweizer C, Lang TH, Ruiz R and Hintermann B. Intraoperative findings of lateral ligament avulsion fractures and outcome after refixation to the fibula. Foot Ankle Int 2018; 39: 669-673.

[17] Lee TH, Jang KS, Choi GW, Jeong CD, Hong SJ, Yoon MA and Kim HJ. The contribution of anterior deltoid ligament to ankle stability in isolated lateral malleolar fractures. Injury 2016; 47: 1581-1585.

[18] Zhao HM, Lu J, Zhang F, Wen XD, Li Y, Hao DJ and Liang XJ. Surgical treatment of ankle fracture with or without deltoid ligament repair: a comparative study. BMC Musculoskelet Disord 2017; 18: 543.

[19] Woo SH, Bae SY and Chung HJ. Short-term results of a ruptured deltoid ligament repair during an acute ankle fracture fixation. Foot Ankle Int 2018; 39: 35-45.

[20] Teramoto A, Shoji H, Sakakibara Y, Suzuki T, Watanabe K and Yamashita T. Suture-button fixation and mini-open anterior inferior tibiofibular ligament augmentation using suture tape for tibiofibular syndesmosis injuries. J Foot Ankle Surg 2018; 57: 159-161.

[21] Marchetti DC, Moatshe G, Phelps BM, Dahl KD, Ferrari MB, Chahla J, Turnbull TL and LaPrade RF. The proximal tibiofibular joint: a biomechanical analysis of the anterior and posterior ligamentous complexes. Am J Sports Med 2017; 45: 1888-1892.

[22] Lange T, Schulte TL, Gosheger G, Schulze Boevingloh A, Mayr R and Schmoelz W. Effects of multilevel posterior ligament dissection after spinal instrumentation on adjacent segment biomechanics as a potential risk factor for proximal junctional kyphosis: a biomechanical study. BMC Musculoskelet Disord 2018; 19: 57.

[23] Massri-Pugin J, Lubberts B, Vopat BG, Wolf JC, DiGiovanni CW and Guss D. Role of the deltoid ligament in syndesmotic instability. Foot Ankle Int 2018; 39: 598-603.