Biomechanical analysis of the impact of fibular osteotomies at tibiotalar joint: A cadaveric study

Lin Yang, Hong-Zhang Xu[1], Dong-Zhu Liang, Wei Lu, Shi-Zheng Zhong, Jun Ouyang

Abstract

Background: Osteotomy of the fibula is a common orthopedic procedure performed for various indications, including harvesting fibula for grafting purposes. The effect of fibular osteotomy and need for tibiofibular syndesmotic fixation fusion at different levels on tibiotalar joint is matter of debate. We performed a biomechanical analysis of the impact of fibular osteotomies at different levels and whether the fixation of distal tibiofibular joint mitigates instability caused by the osteotomy.

Materials and Methods: Six lower limb specimens from fresh adult cadavers were used to prepare leg-foot models. The specimens were assigned to six status according to the level of osteotomy and whether fixation of distal tibiofibular joint was performed or not. Each specimen was then loaded axially to 700 N by the material testing machine, and the tibiotalar joint contact area and peak pressure were measured using an electronic pressure sensor.

Results: The contact area and the pressure of tibiotalar joint showed significant changes when compared to the normal specimen. All osteotomy specimens had a decreased tibiotalar contact area and an increased peak pressure. This positively correlated with proximity of level of osteotomy to the lateral malleolus.

Conclusions: Through this study, we found that fibular osteotomy had an adverse effect in terms of decreasing the contact surface of tibiotalar joint that led to increased peak pressure in the joint. However, bone fusion and screw fixation of the distal tibiofibular joint reduced these adverse effects.

Key words: Biomechanics, fibular osteotomy, tibiotalar joint

Introduction

Partial resection of the fibula is mainly done for using fibula as a graft or for osteomyelitis, fibular tumors, or in cases of trauma with severe bone loss. The implications of fibular resection on the ankle joint have been widely debated.[1-3] It has been shown to cause ankle pain in 10–40% of patients, ankle instability, muscle weakness, and in some cases, functional loss and ankle ectropion malformation in pediatric age groups.[4] Biomechanically, any amount of fibular resection done for any purpose is likely to decrease the contact area of the tibiotalar joint and raise the peak pressure inside the joint. Various researches done in this arena have brought forth diverse conclusions on the length of fibula required to preserve ankle function and avoid any clinically significant complaints.[5] It is universally established that the greater the amount of fibula resection and the more proximal it is to lateral malleolus, the greater the chances of clinical symptoms and instability. Traditionally, the belief is to preserve at least 10% of the length of fibula or roughly 5–7.5 cm[6,7] of the distal fibula. However, there are few clear-cut guidelines based on cadaveric biomechanical studies to substantiate the fact[8]. There is lack of data on biomechanical impact of primary fixation of distal tibiofibular joint following resection of the fibula.

In this cadaveric study, we performed a biomechanical analysis of the impact of fibular resections at different levels and whether the fixation of distal tibiofibular joint mitigates instability caused by the resection. This study is likely to provide a biomechanical basis for optimal length of fibula utilized for graft purposes and also establish guidelines for fixation of distal tibiofibular joint in such cases to prevent occurrences of secondary ankle osteoarthritis.

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Materials and Methods

After obtaining the requisite approval from the Ethics Committee, six fresh adult cadavers were used to procure lower limb samples for the study. None of them had any obvious trauma or deformities on gross examination. The lower limbs were amputated at the knee joint, and the entire leg specimen, including the overlying skin, muscle, and bone, was used for experiment and biomechanical study. All specimens were stored at −20°C for 7 days before the experiment.

Fibula was osteotomized at different levels. We measured the fibula from the fibular head to 6 cm above the lateral malleolus with an average length of 24.78 cm (SD 2.28 cm). We removed the upper part of the fibula at different status into three equal parts: proximal 1/3, middle 1/3, and distal 1/3. Meanwhile, the specimens were measured under six different conditions: normal conditions (N), cutting the proximal third of fibula (A), cutting the middle third of fibula (B1), B1 with tibiofibular fusion (B2), cutting the distal third of fibula (C1), and C1 with tibiofibular fusion (C2). The tibiofibular fusion was achieved by using cortical screws and bone grafts.

The soft tissues was dissected blunt between tibia and fibula until the lateral cortex of tibia was reached. The lateral periosteum of the tibia was dissected by periosteum dissector. The bone block was cutwith the corresponding length from the cutted fibula and implanted into fibular stump between the tibia and fibula. The fibula was drilled thoroughly and bone block was implanted passing thorough the medullary cavity and shin in turn. After sounding and tapping, the cortical bone was fixed by screw and then wound closed layer by layer.

Model preparation

The specimens were stored at −20°C and defrosted at room temperature 12 h before the experiment. First, we performed normal condition testing (no fibula resection) for every specimen and demarcated the beginning and ending positions of planned fibular osteotomy by placing a mark on the fibular bone. Incision was made on the lateral aspect of the shank; after cutting the skin and subcutaneous fascia, blunt dissection of muscles was carried out using the intermuscular plane to access the fibula. The periosteum of the fibula was stripped using a periosteal elevator. The fibula was osteotomized at the indicated place using a gigli saw. In the end, the length of resected fibula was measured and recorded. The wound was closed using 2-0 Ethilon.

Bone fusion and screw fixation

After removing the skin incision, blunt dissection was carried out between the shin of tibia and fibula until the tibia on the opposite side was reached (to the lateral cortex of tibia). The periosteum of the contact area was then elevated using a periosteal elevator[9,10] and the distance between the tibia and fibula was measured at the level of fibular osteotomy. A bone block with the corresponding length from the resected fibula was obtained and implanted into the fibular stump between the tibia and fibula [Figure 1]. Finally, a screw tract was drilled thorough the fibula, bone graft (passing thorough the medullary cavity), and both cortices of tibia. After sounding and tapping, a cortical screw (with length 4.5–6.0 cm) was used to fix them and the wound was then closed in layers.

Sensor selection and implantation

K-scan joint analysis system consists of scanning electronics (called Evolution USB Handle), software, and patented thin-film sensors. This provides a better understanding of how the contact surface of articulating bones is functioning and loading.A flexible electronic pressure sensor (K-Scan Model 5033, 3500 psi; Tekscan, Inc., Boston, MA, USA) with the testing scope [Figure 2] was selected for the purpose of measurement.[10-12] The skin of anterior wall of the joint capsule of the ankle was incised and the subcutaneously soft tissue was carefully separated to reveal the ankle cavity. While carrying out the dissections, care was taken to ensure that the muscle tendon tissues in front of the joint capsule were not damaged. The pressure sensor was then implanted into the ankle cavity ensuring that the implanting position was correct. Prior to use, the sensor was equilibrated using a bladder-type pressure applicator (*I-Scan Bladder Tester*, Tekscan, Inc.) and then calibrated *in situ* in the tibiotalar joint.

Loading of specimens

The specimens with the implanted sensors were placed on the material testing machine (ELF-3510AT, Bose, Inc., Minnesota, USA). The horizontal plates were attached to the soles of the feet of the specimens to imitate standing station of an adult, making sure that the ankles were in neutral position at all times [Figure 3]. 700 N axial load was added using material testing machine with a speed of 50 N/s and kept for 50 s. At the same time, all of the parameters obtained from the ankle specimen were recorded. The above procedure was repeated three times on each specimen, and the average of the data set in each station was recorded as experimental result. The repeated measurements and variance analysis of the dates we completed by SPSS 13.0 (SPSS, Inc., Chicago, USA).

Results

In the normal station, with ankle in neutral position, the contact area of tibiotalar joint was 576.61 mm^2 (SD 55.28 mm^2) and the peak pressure in tibiotalar joint was 3.63 MPa (SD 0.31 MPa) [Table 1]. In all three cases of fibular

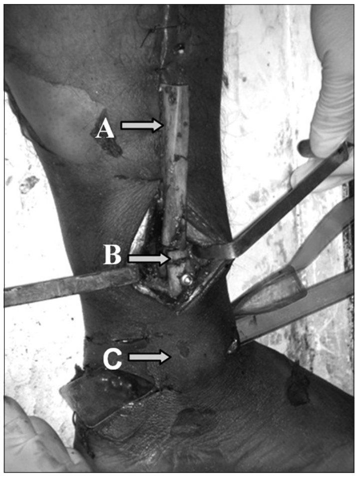

Figure 1: Clinical photograph of the side view of distal 1/3 fibular resection and fixation: A, the fibular resection segment; B, implanted bone; C, lateral malleolus

Figure 2: K-scan pressure sensor and Evolution USB Handle (Tekscan, Inc., Boston, MA). (a) Pressure Sensor (b) USB Handle

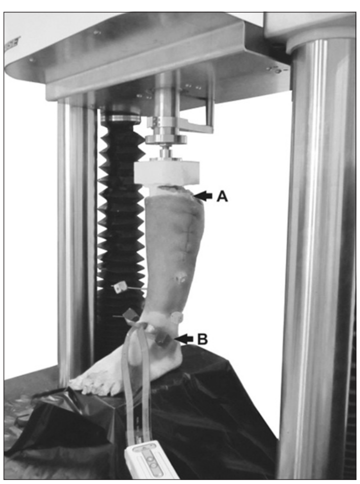

Figure 3: A specimen mounted at neutral position, with pressure sensor inserted in the tibiotalar joint. A, Fibular head; B, lateral malleolus

resection at different levels (proximal, middle, and distal third), the contact area of tibiotalar joint had a significant change ($P < 0.05$) with a decreasing trend. With increasing level of osteotomy, in higher levels, for example, there were lesser contact areas. As a corollary, the peak pressure also had a significant change ($P < 0.05$) with an increasing tendency along with the cutting length of fibula. After cutting the distal third of fibula, the contact area of tibiotalar joint and peak pressure showed a maximum difference ($P < 0.01$) to increasing when compared with the normal case. A second set of measurements was carried out in the group where fusion of the distal tibiofibular joint was done. In these two cases, the contact areas of tibiotalar joint had a significant difference ($P < 0.05$) and the peak pressure also changed significantly [Table 2] ($P < 0.01$).

Discussion

Fibular resection is carried out for using the fibula as bone graft. The studies done in the past have demonstrated that there is biomechanical impact of the procedure on the ankle joint. These studies have suggested that the amount of resection and the distance of resection level from lateral malleolus have a bearing on the function of the ankle joint. The amount and exact degree of the resection have not been quantified in detail in various biomechanical studies that have been conducted[14] It also remains to be conclusively proven whether the fusion of distal tibiofibular joints has an impact on the functional outcome and any improvement in biomechanics.[15,16] Few researchers in the past have elucidated the effect of fibular coloboma on the contact characteristics of tibiotalar joint.[11,17] Fibular coloboma would change the contact area of the tibiotalar joint, whether caused secondary to trauma or from deliberate clinical bone grafting. With improvement in techniques of biomechanical analysis, such as the ones used in this study, it was realized that after resection of fibula there were significant changes in tibiotalar contact area and peak stresses at the joint level. After biomechanical analysis of fibular osteotomy at different degrees in fresh foot static specimens, Pacelli *et al.* found that in resections where more than 10% of the fibula was preserved, there was no change in movement of the ankle. If less than 10% of the fibula remains, movement of ankle would lead to pain and instability, which is more pronounced during ankle varus and external rotation.[11] A majority of researchers also thought that the abbreviated fibula tends to shift outward, causing the external region of articular surface in trochlea of talus and the medial area of articular surface in inferior extremity of tibia to lose their corresponding articular surface, thus causing partial loss of articular surface of tibiotalar joint.[12,13,18]

In clinical application, there is no consensus on the impact of the length of fibula after resection on the functional outcome.[19,20] Up to now, scholars have thought if more than

Table 1: The variance of the contact area and peak press of tibiotalar joint after cutting the fibula in different status

Item (*N* = 6)	Fibula cutting in different status						*F*	*P*
	N	A	B1	B2	C1	C2		
Contact area (mm^2)	576.61 (55.28)	461.67 (52.98)	447.89 (43.23)	471.06 (56.01)	432.06 (72.87)	563.11 (63.95)	22.940	0.000
Peak stress (Mpa)	3.63 (0.31)	4.18 (0.46)	4.37 (0.67)	4.04 (0.34)	4.84 (0.32)	3.78 (0.54)	20.958	0.000

Table 2: Multiple comparisons on the contact area and peak pressure of tibiotalar joint under fibular osteotomy in different degrees

Status (I)	Status (J)	Contact area			Peak stress		
		Mean difference (I − J)	Std. error	Sig. (a)	Mean difference (I − J)	Std. error	Sig. (a)
N	A	114.945(*)	4.519	0.000**	−0.557(*)	0.129	0.008**
	B1	128.772(*)	6.374	0.000**	−0.740(*)	0.227	0.022**
	B2	105.555(*)	3.216	0.000**	−0.402(*)	0.138	0.009**
	C1	144.557(*)	9.616	0.000**	−1.213(*)	0.180	0.000**
	C2	13.503	5.274	0.051	−0.152	0.136	0.474
A	B1	13.777	3.118	0.074	−0.183	0.184	0.365
	C1	29.612(*)	7.381	0.032	−0.657(*)	0.130	0.004**
B1	B2	−23.117(*)	5.267	0.009**	0.338	0.272	0.269
	C1	15.835(*)	12.593	0.264	−0.473(*)	0.152	0.027
C1	C2	131.053(*)	5.794	0.000**	1.062(*)	0.094	0.000**

*: $P<0.05$, **: $P<0.01$

5 cm of fibula is preserved at distal end, the resection would not influence ankle function.[21] After resecting a segment of fibula, since contact area of tibiotalar joint deflates and shifts, the mean stress increases and crest value pressure area gets redistributed. Normal weight loading areas shift to the primary, non-weight loading area, leading to synovial effusion and thereby depriving joint cartilage of critical nutritional ingredients from synovial fluid. This can result in cartilage cells becoming pyknotic, and in this circumstance, necrosis tends to ensue due to lack of materials and water. The end result of this cascade is deterioration in joint function and eventual arthritis.

This study has demonstrated that cutting equal length bone block in different parts of the fibula has different consequences on contact area and crest value stress of tibiotalar joint. When osteotomized at the distal third portion of the fibula, there are significant differences in tibiotalar joint contact area and crest value stress compared with the complete fibula. When the proximal 2/3 of fibula is cut, the relevant data of tibiotalar joint also has similar differences. However, when the distal 1/3 is cut, although the result still significantly differs from normal test values, the effect is less than the former two.

The current study proved that increasing the length of resection directly correlates with a decrease in the articular surface of tibiotalar joint and inversely correlates with the joint crest value stress. Distal fibula plays a significant role in the inferior tibiofibular syndesmosis which participates in stress distribution in the articular surface of lateral malleolus and tibiotalar joint through hand spike principle.[22,23] Fibular length decreases after partial osteotomy, which changes continuity of tibia stress distribution, and as a result, affects stability of tibiofibula combination as well as the abnormal stress and function in the ankle. Therefore, we performed clinical bone graft fusion-stabilization to improve the ankle stability. Contact area and crest value pressure of tibiotalar joint were measured with repeated loading experiments, which revealed notable changes in specimens after intervention compared with those before intervention. Fixing the fibula stump not only could recover the stable mechanics in the distal tibiofibular syndesmosis, but also improved contact characteristics the in gravity conduction process of tibiotalar joint. In summary, surgical intervention in the form of stabilization of distal tibiofibular joint to fibular osteotomy has certain clinical applications.

Conclusion

Our study represented preserving as much of the length of the fibula as possible, the proximal 1/3 to middle 1/3 during fibular grafting or osteotomy, would prevent adverse effects on functional outcome. If doing bone grafting and more than middle 1/3 of fibula needs resection, the proper fixation methods should be performed using screws and graft to ensure the tibiotalar joint stability. Furthermore, this would ensure fine contact area of the tibiotalar joint, avoid excessive crest value stress that can destroy the tibiotalar joint, and then recovery contact characteristics would return to normal levels postoperatively. The resection of middle or distal fibula has significant effects on tibiotalar joint stability.

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