The Effects of Medial Soft Tissue Release for Varus Deformity during Medial Open Wedge Supramalleolar Osteotomy: A Cadaveric Study

Dai-Soon Kwak
Catholic University of Korea
Inha Woo
Yeungnam University Medical Center
Jung-min Lee
Inje University
Chul Hyun Park (chpark77@naver.com)
Yeungnam University

Research Article

Keywords: Ankle, Osteoarthritis, Supramalleolar osteotomy, Fibular osteotomy

Posted Date: June 26th, 2023

DOI: https://doi.org/10.21203/rs.3.rs-3060803/v1

Abstract

Background

The supramalleolar osteotomy (SMO) can redistribute the mechanical axis and balance the load on the joint in the varus ankle osteoarthritis. The purpose of this study was to investigate not only the effect of fibular osteotomy but the effects of release of medial soft tissue (posterior tibialis tendon (PTT), deep deltoid ligaments) which act as medial stabilizing structures in medial open wedge SMO.

Methods

Twelve fresh frozen human legs were obtained and disarticulated below the knee. All experiments were conducted in four steps. First, medial open wedge tibial osteotomy was done. Second, a fibular osteotomy was performed in an inferomedial direction at the same level as that of the tibial osteotomy. Third, the deep deltoid ligament was released from the tibial attachments. Last, the total tenotomy of the PTT was performed behind the medial malleolus. After finishing each step, contact area, peak pressure and mean pressure were measured in the tibiotalar and talofibular joints.

Results

Fibular osteotomy after medial open wedge SMO significantly decreased the mean and peak pressures in the talofibular joint. The medial soft tissue release showed a remarkable lateral shift and decrease in tibiotalar joint loading.

Conclusions

Surgeons should take into account these effects of fibular osteotomy and medial soft tissue release in open wedge SMO. Adequate release of the deltoid ligament and PTT could be a useful technique to minimize the tibiotalar joint stress.

Background

In the treatment of varus ankle osteoarthritis (OA), supramalleolar osteotomy (SMO) is a representative joint preservation surgery by correcting the weight-bearing axis and the load transfer across the ankle joint. [1, 2] Since Takakura et al. reported his results of medial open wedge SMO for treating post-traumatic varus distal tibial deformities, many literatures have advocated its results so far.[3, 4] In most patients, especially with an asymmetric varus ankle OA in which talus is tilted into varus within the ankle mortise, a medial open wedge osteotomy is usually enough to correct the deformity.[5]

There are still multiple surgical issues followed by medial open wedge SMO.[6] Concomitant fibular osteotomy has pros and cons. It can shift the mechanical axis further laterally and reduces the risk of developing pain due to subfibular impingement.[6] Some authors have suggested that radiologic values such as talar tilt and medial displacement of the talus significantly decreased after combined fibular osteotomy.[7, 8] Whereas, Ahn et al. reported significant improvements of clinical scores (Visual analog scale (VAS) and American Orthopeaedic Foot & Ankle Society (AOFAS) scores) from cohort study of patients who received SMO without fibular osteotomy.[9] Due to these contrary results, definite indications of fibular SMO have not been decided.

A correct soft tissue balance keeps the joint aligned in range of motion.[10] In case of the ankle joint, the deltoid ligament complex and posterior tibialis tendon (PTT) are the most important dynamic medial stabilizers.[11, 12] Due to the presence of substantial medial soft tissue contracture with a severe varus deformity of the ankle joint, adequate medial soft tissue balance is crucial to obtain the desired deformity correction.[13] Whereas, the insufficiency of the medial soft tissue structures by excessive release may break down the medial longitudinal arch. However, as far as we know, there are few surgical indications or biomechanical studies on medial soft tissue balancing accompanied by SMO.

The purpose of this study was to investigate the effect of combined fibular osteotomy and medial soft tissue release on the tibiotalar and talofibular joints through cadaveric medial open wedge SMO models. We hypothesized that SMO with combined fibular osteotomy and medial soft tissue release would reduce the tibiotalar joint stress and increase the talofibular joint stress.

Materials and Methods

Specimen preparations

We obtained 12 fresh-frozen human legs from five male and one female donor, with a mean age of 73.6 years (50–84) years. A normal range of motion in the ankle joint was checked clinically, and malalignment was excluded radiologically. All the specimens were thawed at room temperature for at least 24 hours. Disarticulation was performed at the knee joint and the medullary canal was drilled. A customized load transmitter with a stem in the tibial medullary canal was used to apply the axial load. The skin and subcutaneous tissues were dissected around the ankle join. To preserve as much soft tissue as possible, the interosseous membranes, ligaments and tendons remained intact. Each leg was held upright inside the load frame and a universal testing machine (Instron, Model 5567, Norwood, MA, USA) stimulated the single-leg barefoot stance. A custom-made calibration jig was mounted to the Instron actuator. The forefoot was strapped for stabilization. (Fig. 1)

Contact area, mean pressure and peak pressure were evaluated in the tibiotalar and talofibular joints by a pressure mapping sensor K-scan 6900 system (Tekscan, South Boston, MA, USA). All measurements were calibrated according to the manufacturer’s guidelines beforehand. The sensor array played a role in receiving and transmitting information to the system. Two of four independent sensor arrays were used.

Each sensing array had a 196 mm^2 matrix area (14 mm x 14 mm), 121 sensels (11 x 11), and a density of 62.0 sensels/cm^2. Sensel refers to the basic element of the loading sensing area. To insert the sensors into the tibiotalar and talofibular joints, arthrotomies including anterior, posterior, lateral ankle joint were performed. To prevent the sensors sliding or damaged, the edges of sensors were connected by Vicryl 2 – 0 sutures with two additional screws were inserted into the non-articular area of the calcaneum (Fig. 1).

Biomechanical Testing

15 preconditioning cycles with a 700N loading, then the static axial compression was increased continuously form 50N preload to 700N representing a single-leg stance with a mean body weight. [14] Maximum load was held for 2 seconds, Contact area, peak and mean pressures were recorded for analysis. Peak pressures were captured at 50 Hz and peak pressure distribution was captured until the load was released. [15, 16]

Surgical Procedures

Before the surgical procedures, the intact values of the specimen were recorded after the dissection. All surgical procedures were performed by a senior orthopaedic surgeon (C.H.P.). All the procedures were made in four steps. First medial open wedge tibial osteotomy, heading for the proximal syndesmosis, was performed. Medial open wedge SMO was performed as described previously.[17] The osteotomy plane was initiated 4–5 cm proximal to the tip of the medial malleolus.[18] Multiple drilling using a Kirschner wire were performed at the lateral cortex of the osteotomy site to preserve the lateral cortex. A complete osteotomy was performed by inserting a thin osteotome. After osteotomy, the osteotomy site was fixed using an anatomical locking plate (Ohtofix, Ohtomedical Co. Ltd., Goyang, Korea) with a metal block (height 9 mm). The identical osteotomy gap (9 mm) was decided in order to unify the difference according to the gap. Second, fibular osteotomy was performed in an inferomedial direction at the same level as that of tibial osteotomy.[19] The fibular osteotomy site was fixed using an anatomical locking plate (Ohtofix, Ohtomedical Co. Ltd., Goyang, Korea). Third, the deep deltoid ligament was released at the tibial attachment, being cautious not to damage the superficial deltoid ligament.[20] Finally, a total tenotomy of the PTT was performed behind the medial malleolus. (Fig. 2) Special care was taken not to injure other structures. After each step, all the parameters were evaluated with K-scan.

Statistical Analysis

A priori power analysis based on a previous biomechanical study suggested that 11 specimens would provide a statistically significant difference in MPa with a standard deviation of 0.8 at a P-value of 0.05. [17] Statistical analyses were performed using the SPSS for Windows, version. 16.0.0, software package (SPSS Inc., Chicago, IL, USA). The continuous variables were initially assessed for normality test using the Shapiro-Wilk test due to small sample sizes.[21] Mean and standard deviation were also calculated. For variables where the assumption for normality appeared to be satisfied, t-test was used. For nonparametric groups that did not follow a normal distribution, the Mann-Whiteney U test was used. Statical significance was set at p-value < 0.05.

Results

The contact area, mean pressure and peak pressure in the tibiotalar joint are shown in Fig. 3 and Table 1. The linear mixed model was used to determine the effects of each surgical procedure on the parameters measured by the K-scan. Tibial osteotomy increased the contact area, mean pressure and decreased peak pressure than the intact value. ($p < 0.05$) Afterwards, fibular osteotomy significantly decreased the mean pressure in the talar dome than the previous step. ($p = 0.019$) Deltoid ligament and PTT tenotomy then decreased the contact area and peak pressure respectively compared to the previous step. ($p = 0.027$, $p = 0.033$)

Figure 4 and Table 1 provide the changes in the talofibular joint. All values were compared with those of the previous step. All values increased significantly after tibia osteotomy was performed ($p < 0.01$) and decreased thereafter. In particular deltoid ligament release remarkably decreased the peak pressures. ($p = 0.027$) PTT tenotomy made a non-significant change in all parameters. ($p > 0.05$)

The peak pressure distribution on the talar dome at each surgical step is presented in Fig. 5. Each sensing array consists of 121 sensels. (11 x 11) Initially, most of the peak pressures were located central to medial side of the talar dome. Each surgical step then lateralized. At the final step, most of the peak pressure positions were located on the lateral side of the talar dome.

Table 1. Biomechanical outcomes of different conditions (mean ± standard deviation). Every p-value was compared to the value of the intact value.

Parameters		Tibiotalar joint		Talofibular joint	
		Estimation (mean ± SD)	***p*-value**	**Estimation (mean ± SD)**	***p*-value**
Contact Area (mm2)	Intact	137.9 ± 20.3		36.3 ± 5.1	
	Tibia	146.3 ± 5.9	< 0.01	65.3 ± 10.8	< 0.01
	Fibula	162.1 ± 7.1	< 0.01	66.6 ± 9.9	0.026
	Deltoid	144.8 ± 6.0	0.131	56.5 ± 10.6	0.041
	PTT	135.6 ± 9.8	0.933	51.6 ± 9.4	0.059
Peak Pressure (KPa)	Intact	6845 ± 495		266.5 ± 77.2	
	Tibia	5782 ± 605	0.021	1514.1 ± 541.1	< 0.01
	Fibula	5429 ± 570	0.073	2615.5 ± 298.9	< 0.01
	Deltoid	5066 ± 705	0.026	2178.1 ± 312.5	< 0.01
	PTT	4310 ± 707	< 0.01	2145.0 ± 339.3	< 0.01
Mean Pressure (KPa)	Intact	1529 ± 110		18.3 ± 8.2	
	Tibia	1587 ± 132	0.409	328.9 ± 95.3	< 0.01
	Fibula	1497 ± 186	0.911	238.3 ± 45.7	< 0.01
	Deltoid	1340 ± 210	0.134	219.7 ± 47.8	< 0.01
	PTT	873 ± 214	0.013	190.1 ± 47.0	< 0.01

Discussion

SMO is a well-accepted treatment method for mid-staged varus ankle osteoarthritis. [22] It also has multiple surgical issues regarding the necessity of combined fibular osteotomy or adequate indications of soft tissue release. Furthermore, little is known about the effects of releasing medial soft tissue. Our strength of the present study was to investigate biomechanical effects of combined fibular osteotomy and medial soft tissue release in tibiotalar and talofibular joints according to the authors' desired surgical steps.

Choi et al. stated that medial open wedge SMO combined with fibular osteotomy can cause more lateral translation of the talus than the one without fibular osteotomy.[23] They also reported that combined fibular osteotomy decreased the talofibular joint pressure that had increased after tibial osteotomy, but it did not influence the tibiotalar joint pressure. Our cadaveric study results coincide with these findings, revealing that remarkable decrease of peak and mean pressure in the talofibular joint and a lateral talar shift on the talar dome were obtained after fibular osteotomy. This implies that fibular osteotomy might be necessary step in medial open wedge SMO for decreasing the loading in the talofibular joint.

The deltoid ligament, also known as the medial collateral ligament complex of the ankle joint, is a strong, broad ligament from the medial malleolus toward the talus, calcaneus and navicular bone. It is widely known that the deltoid ligament is separated into a superficial and a deep layer.[24] Besides maintaining medial ankle stability, the superficial portion of the medial ankle plays an important role in maintaining rotational ankle stability. Rasmussen et al.[25, 26] reported the various functions of deltoid ligament and investigated the superficial layers specifically limiting talar abduction. Hintermaan et al. stated that the loss of tibionavicular ligament and the tibiospring ligament allow the occurrence of an increase in internal rotation of the lower leg, leading to symptomatic instability or laxity of the anterior talofibular ligament.[24] Whereas the loss of deep portion of deltoid ligament including anterior tibiotalar ligament and posterior tibiotalar ligament can shift its center of rotation laterally and thus resulting in a lateral shift of the articular load.[27] Therefore, we considered releasing deep layers of the deltoid ligament met the purpose of SMO, that is a lateral shift of center of rotation (COR).

In patients with a varus ankle osteoarthritis, the remaining inframalleolar deformity may be the results of the medial soft tissue contractures. Overactivity of PTT may be a contributing factor of spastic ankle varus deformity.[28] Hintermann et al.[13] recommended releasing PTT with patients who had severe ankle varus osteoarthritis with contractures. However, there is a paucity of how to obtain appropriate medial soft tissue balance in medial open wedge SMO. The PTT is primarily responsible for plantar flexion and inversion of the foot and highly associated with flatfoot deformity, therefore we judged that PTT would be the last resort to be handled to correct varus deformity.[29, 30] Park et al. stated that PTT transfer often combined with bony alignment procedures would be a reasonable option for painful varus ankle arthritis with hindfoot varus. [17] Transferring PTT could convert the deforming force to reduction force of varus ankle arthritis. Based on our results of study, although we decided to perform PTT tenotomy rather than PTT transfer, PTT tenotomy at the final step caused significant decrease of mean and peak pressure in the tibiotalar joint. Therefore, the surgeon should predict concomitant PTT and deltoid ligament release can lead to unpredictable gap increments and over-release problems. It is recommended that intraoperatively confirming adequate soft tissue balance is necessary.

Our study had some limitations. First, in the present study, we aimed to investigate the effects of concomitant fibular osteotomy and medial soft tissue release. SMO is not only correcting the coronal deformity but also affecting the sagittal plane deformity, subtalar motion and hindfoot alignment. Due to the complexity, it was challenging to take into account these variables. Therefore, additional research such as a finite element analysis can simulate actual mechanisms of the lower leg. Second, most of the specimens in the present study had no medial ankle osteoarthritis, unlike our aim of treating medial ankle osteoarthritis with SMO. Although the results of this study may be different in patients with actual ankle arthritis, it was judged to have a strength in showing the tendency how the pressures and contact area change according to various surgical procedures. Finally, all specimens underwent identical sequential surgical steps in the order of the tibial osteotomy, fibular osteotomy, deltoid ligament release and PTT tenotomy. It was noted that the medial stabilizing force rapidly weakened after PTT was released. Therefore, all steps following PTT release intraoperatively might be interpreted. Depending on the surgeon's preference, either PTT or the deltoid may be released in some cases.

In conclusion, fibular osteotomy after medial open wedge SMO significantly decreased the loading of mean and peak pressure of the talofibular joint. The medial soft tissue release showed a remarkable lateral shift and decrease in tibiotalar joint loading. Therefore, surgeons should take into account these effects of fibular osteotomy and medial soft tissue release in open wedge SMO. Adequate release of the deltoid ligament and PTT could be a useful technique to minimize the tibiotalar joint stress.

List Of Abbreviations

Supramalleolar osteotomy (SMO)

Posterior Tibialis Tendon (PTT)

Osteoarthritis (OA)

Declarations

Ethics approval and consent to participants: This study was conducted following the approval of the Institutional review board of Catholic University Hospital Soonchunhyang University Bucheon Hospital. (reference No. **MC21EIDI0149)**. All cadavers were supported by the of Anatomy, Catholic University, Seoul, Republic of Korea. Patient consent was waived due to this study being a cadaveric study. Therefore, it was not possible to identify participants.

Consent for publication: This manuscript does not contain data from any individual person.

Availability of data and materials: The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests: The authors declare that they have no competing interests

Funding: This research was supported by a grant from the MD-PhD/Medical Scientist Training Program through the Korea Health Industry Development Institute (KHIDI), funded by the Ministry of Health & Welfare, Republic of Korea.

Author Contributions: Dai-Soon Kwak and Inha Woo have contributed to this study equally (Co-1st authors). Inha Woo and Chul Hyun Park Woo conceived and designed the experiments. Jung-Min Lee, Dai-Soon Kwak and Chul Hyun Park performed the searches and experiments. Inha Woo and Jung-Min Lee analyzed and interpreted data. Inha Woo and Dai-Soon Kwak wrote the manuscript. Chul Hyun Park reviewed the manuscript. All authors read and approved the final manuscript.

Acknowledgments: Not Applicable

References

1. Colin F, Gaudot F, Odri G, Judet T. Supramalleolar osteotomy: techniques, indications and outcomes in a series of 83 cases. Orthop Traumatol Surg Res. 2014;100(4):413-8.
2. Greenfield J, Appelmann P, Lafon Y, Bruyère-Garnier K, Rommens PM, Kuhn S. A comparative biomechanical study of the Distal Tibia Nail against compression plating for the osteosynthesis of supramalleolar corrective osteotomies. Scientific Reports. 2021;11(1):18834.
3. Tanaka Y, Takakura Y, Kumai T, Samoto N, Tamai S. Radiographic analysis of hallux valgus. A two-dimensional coordinate system. JBJS. 1995;77(2).
4. Colin F, Gaudot F, Odri G, Judet T. Supramalleolar osteotomy: Techniques, indications and outcomes in a series of 83 cases. Orthopaedics & Traumatology: Surgery & Research. 2014;100(4):413-8.
5. Becker AS, Myerson MS. The indications and technique of supramalleolar osteotomy. Foot Ankle Clin. 2009;14(3):549-61.
6. Choi GW, Lee SH, Nha KW, Lee SJ, Kim WH, Uhm C-S. Effect of Combined Fibular Osteotomy on the Pressure of the Tibiotalar and Talofibular Joints in Supramalleolar Osteotomy of the Ankle: A Cadaveric Study. The Journal of Foot and Ankle Surgery. 2017;56(1):59-64.
7. Zhao H, Liang X, Li Y, Yu G, Niu W, Zhang Y. The role of fibular for supramalleolar osteotomy in treatment of varus ankle arthritis: a biomechanical and clinical study. J Orthop Surg Res. 2016;11(1):127.
8. Liang JQ, Wang JH, Zhang Y, Wen XD, Liu PL, Liang XJ, et al. Fibular osteotomy is helpful for talar reduction in the treatment of varus ankle osteoarthritis with supramalleolar osteotomy. J Orthop Surg Res. 2021;16(1):575.
9. Ahn TK, Yi Y, Cho JH, Lee WC. A cohort study of patients undergoing distal tibial osteotomy without fibular osteotomy for medial ankle arthritis with mortise widening. J Bone Joint Surg Am. 2015;97(5):381-8.
10. Meloni MC, Hoedemaeker RW, Violante B, Mazzola C. Soft tissue balancing in total knee arthroplasty. Joints. 2014;2(1):37-40.
11. Chhabra A, Soldatos T, Chalian M, Faridian-Aragh N, Fritz J, Fayad LM, et al. 3-Tesla magnetic resonance imaging evaluation of posterior tibial tendon dysfunction with relevance to clinical staging. J Foot Ankle Surg. 2011;50(3):320-8.
12. Ziai P, Benca E, Skrbensky GV, Wenzel F, Auffarth A, Krpo S, et al. The role of the medial ligaments in lateral stabilization of the ankle joint: an in vitro study. Knee Surg Sports Traumatol Arthrosc. 2015;23(7):1900-6.
13. Hintermann B, Knupp M, Barg A. Supramalleolar Osteotomies for the Treatment of Ankle Arthritis. J Am Acad Orthop Surg. 2016;24(7):424-32.

14. Lee KB, Cho YJ. Oblique supramalleolar opening wedge osteotomy without fibular osteotomy for varus deformity of the ankle. Foot Ankle Int. 2009;30(6):565-7.
15. Kuhn S, Appelmann P, Pairon P, Mehler D, Rommens PM. The Retrograde Tibial Nail: presentation and biomechanical evaluation of a new concept in the treatment of distal tibia fractures. Injury. 2014;45 Suppl 1:S81-6.
16. Stufkens SA, van Bergen CJ, Blankevoort L, van Dijk CN, Hintermann B, Knupp M. The role of the fibula in varus and valgus deformity of the tibia: a biomechanical study. J Bone Joint Surg Br. 2011;93(9):1232-9.
17. Park CH, Kim JB, Kim J, Yi Y, Lee WC. Joint Preservation Surgery for Varus Ankle Arthritis with Large Talar Tilt. Foot Ankle Int. 2021;42(12):1554-64.
18. Lee WC, Moon JS, Lee K, Byun WJ, Lee SH. Indications for supramalleolar osteotomy in patients with ankle osteoarthritis and varus deformity. J Bone Joint Surg Am. 2011;93(13):1243-8.
19. Myerson MS, Zide JR. Management of varus ankle osteoarthritis with joint-preserving osteotomy. Foot Ankle Clin. 2013;18(3):471-80.
20. Coetzee JC. Management of Varus or Valgus Ankle Deformity with Ankle Replacement. Foot and Ankle Clinics. 2008;13(3):509-20.
21. Lobao MH, Melvani RT, Abbasi P, Parks BG, Murthi AM. Dermal allograft superior capsule reconstruction biomechanics and kinematics. J Shoulder Elbow Surg. 2021;30(9):2156-65.
22. Zhao H, Liang X, Li Y, Yu G, Niu W, Zhang Y. The role of fibular for supramalleolar osteotomy in treatment of varus ankle arthritis: a biomechanical and clinical study. Journal of Orthopaedic Surgery and Research. 2016;11(1):127.
23. Choi GW, Lee SH, Nha KW, Lee SJ, Kim WH, Uhm CS. Effect of Combined Fibular Osteotomy on the Pressure of the Tibiotalar and Talofibular Joints in Supramalleolar Osteotomy of the Ankle: A Cadaveric Study. J Foot Ankle Surg. 2017;56(1):59-64.
24. Hintermann B, Golanó P. The Anatomy and Function of the Deltoid Ligament. Techniques in Foot & Ankle Surgery. 2014;13(2).
25. Rasmussen O, Kromann-Andersen C, Boe S. Deltoid ligament. Functional analysis of the medial collateral ligamentous apparatus of the ankle joint. Acta Orthop Scand. 1983;54(1):36-44.
26. Rasmussen O, Tovborg-Jensen I. Mobility of the ankle joint: recording of rotatory movements in the talocrural joint in vitro with and without the lateral collateral ligaments of the ankle. Acta Orthop Scand. 1982;53(1):155-60.
27. Close JR. Some applications of the functional anatomy of the ankle joint. J Bone Joint Surg Am. 1956;38-a(4):761-81.
28. Vlachou M, Dimitriadis D. Split tendon transfers for the correction of spastic varus foot deformity: a case series study. J Foot Ankle Res. 2010;3:28.
29. Lhoste-Trouilloud A. The tibialis posterior tendon. J Ultrasound. 2012;15(1):2-6.

30. Semple R, Murley GS, Woodburn J, Turner DE. Tibialis posterior in health and disease: a review of structure and function with specific reference to electromyographic studies. Journal of Foot and Ankle Research. 2009;2(1):24.

Figures

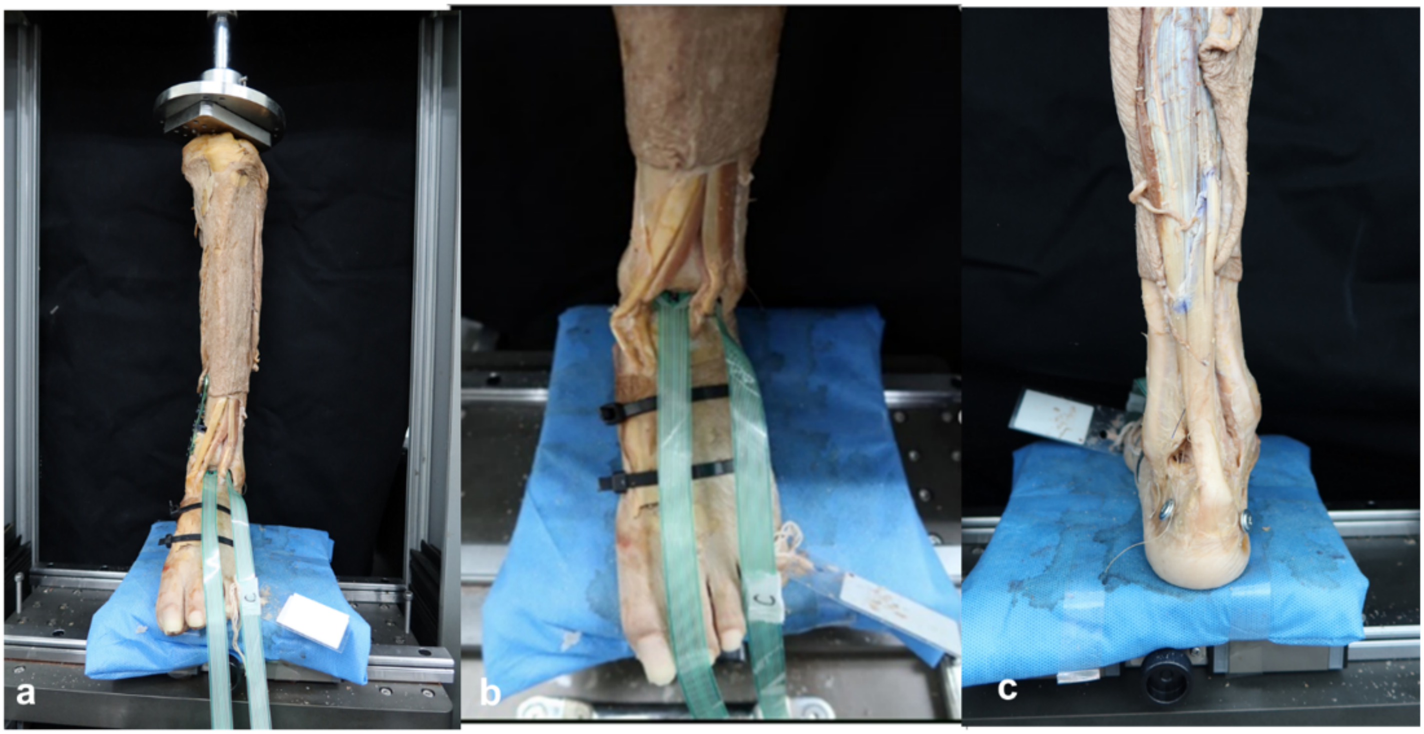

Figure 1

Biomechanical test of the lower leg (a)The disarticulated lower leg was held in upright position. The leg is free-standing, stabilized by a forefoot strap and secured by the pressure of the axial load. (b) TekScan sensors were inserted into the tibiotalar and talofibular joints. (c) To prevent the sensors sliding or damaged, the edges of sensors were connected by Vicryl 2-0 sutures with two additional screws were inserted into the non-articular area of the calcaneum.

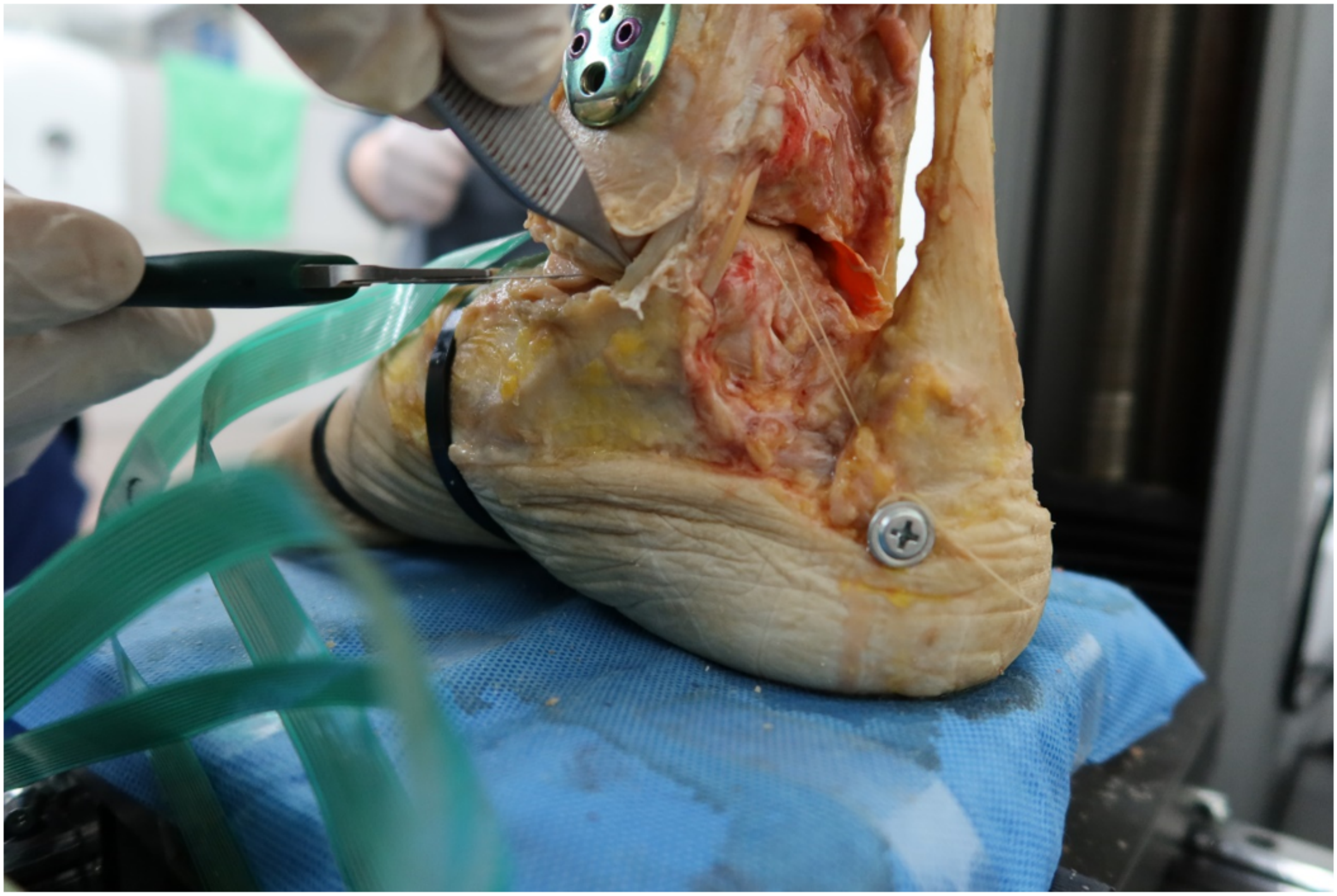

Figure 2

Posterior tibialis tendon (PTT) was released posterior to the medial malleolus. Special care was taken not to injure other anatomical structures.

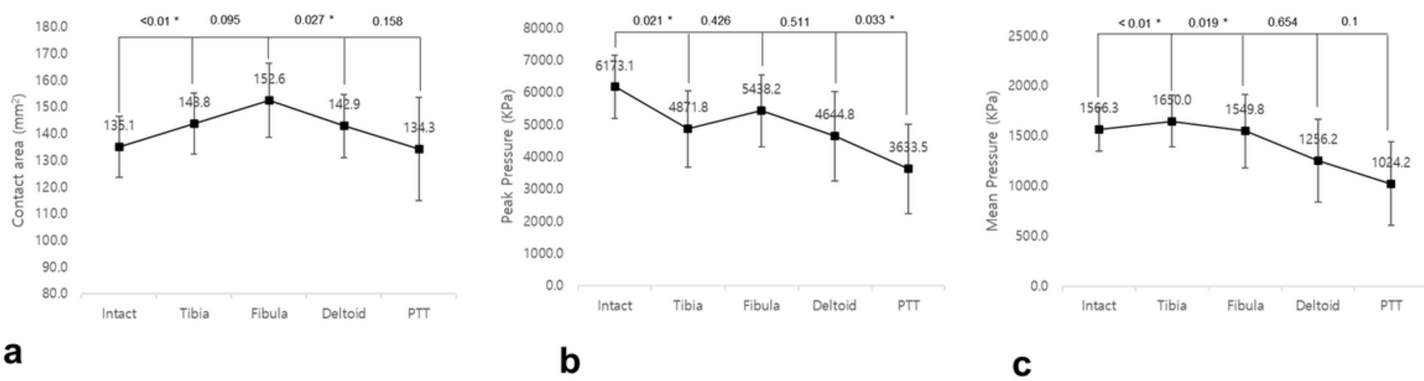

Figure 3

Changes of measurements in the tibiotalar joint during the surgical procedures in order. (a) Contact area (b) peak pressure (c) mean pressure. Every value was compared with the value of previous step. If a p-value is less than 0.05, it is flagged with an asterisk (*).

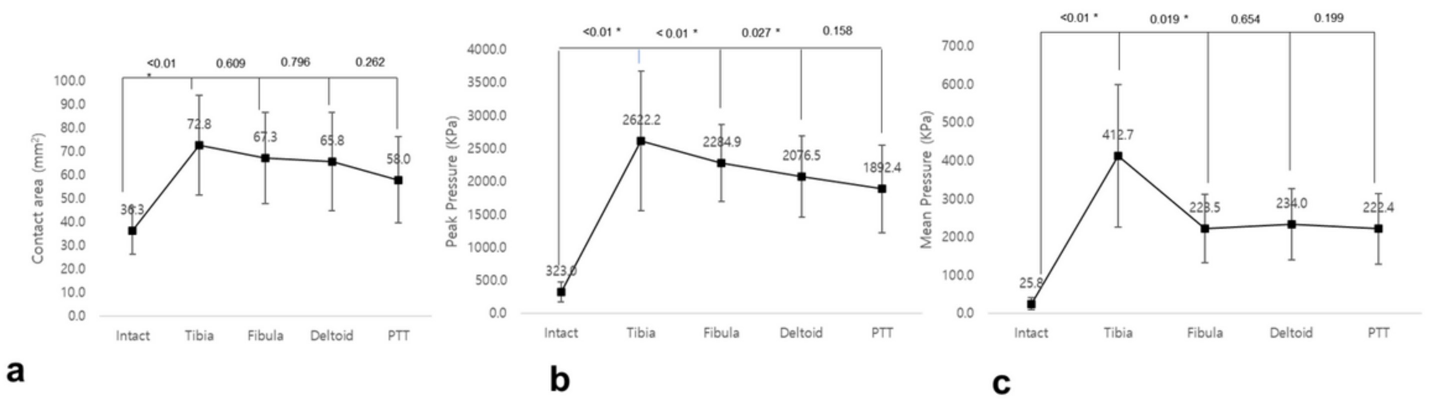

Figure 4

Changes of measurements in the talofibular joint during the surgical procedures in order. (a) Contact area (b) peak pressure (c) mean pressure. Every value was compared with the value of previous step. If a p-value is less than 0.05, it is flagged with an asterisk (*).

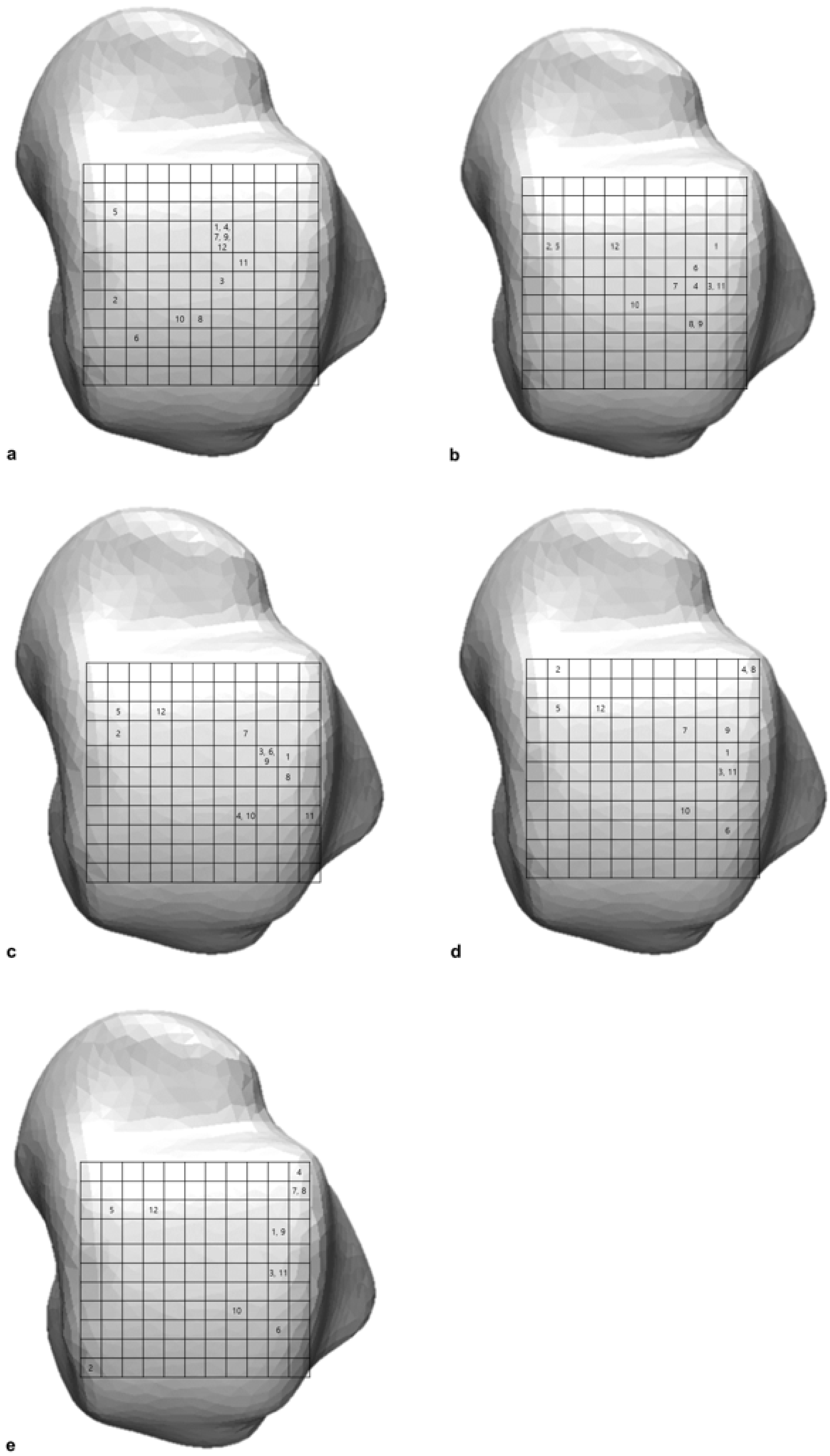

Figure 5

Tibiotalar joint peak pressure distribution on the talar dome. Each sensing array consists of 121 sensels. (11 x 11) The positions of the peak pressures of 12 specimens in each surgical procedure were indicated. Each number stands for the specimen in order. (a) intact (b) after tibial osteotomy (c) after fibular osteotomy (d) after deltoid ligament released (e) after PTT was released.