Original article

Assessment of subtalar joint neutral position: a cadaveric study

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***Keywords:** subtalar joint; biomechanics; kinematics*

Background Subtalar joint (STJ) neutral position is the position typically used by clinicians to obtain a cast representation of a patient's foot before fabrication of biomechanical functional orthosis. But no method for measuring STJ neutral position has been proven accurate and reproducible by different testers. This study was conducted to investigate the STJ neutral position in normal feet in cadavers.

Methods Twelve fresh-frozen specimens of amputated lower legs were used. Pressure-sensitive films were inserted into the anterior and posterior articulation of STJ. The contact areas for various foot positions and under axial loads of 600 N were determined based on the gray level of the digitized film. The STJ neutral positions were determined as the ankle-foot position where the maximum contact area was achieved, because the neutral position of a joint was defined as the position where the concave and convex surfaces were completely congruous.

Results In ankle-foot neutral position, the contact area of STJ was (2.79±0.24) cm^2. In the range of motion of adduction-abduction (ADD-ABD), the maximum contact area was (3.00±0.26) cm^2 when the foot was positioned 10° of ABD (F=221.361, P <0.05). In the range of motion of dorsiflexion-plantarflexion (DF-PF), the maximum contact area was (3.61±0.25) cm^2 when the foot was positioned 20° of DF (F=121.067, P <0.05). In the range of motion of inversion-eversion (INV-EV), the maximum contact area was (3.14±0.26) cm^2 when the foot was positioned 10° of EV (F=256.252, P <0.05).

Conclusions Joints, such as STJ, therefore, are not necessarily in neutral position when the ankle-foot is placed in the traditional concept of neutral position. The results demonstrate that the most approximate STJ neutral position was in the foot position of 10° of abduction, 20° of dorsiflexion and 10° of eversion.

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The subtalar joint (STJ) is one of the most complex weight-bearing joints. Minor biomechanical or anatomical details may often have considerable clinical significance. The STJ is responsible for the conversion of the rotatory forces of the lower extremities and dictates the movements of the midtarsal joints and the forefoot.[1] Subtalar neutral is the position typically used by clinicians to obtain a cast representation of a patient's foot before fabrication of biomechanical functional orthosis. However, no one method for measuring STJ neutral has been proven accurate and reproducible by different testers.[2]

The neutral position of a joint can be defined as the position where the concave and convex surfaces are completely congruous. This definition has been changed and modified by various researchers when referring to the STJ neutral position. In addition, there are different opinions in the literature as to the true definition of the STJ neutral position and the best methods for its measurement.[3-8] These various opinions have created a controversy about STJ neutral position.

This *in vitro* study was designed primarily to evaluate the STJ neutral position by measurement of contact areas in the subtalar joint under axial loads and in different foot positions.

METHODS

Materials

Twelve fresh-frozen cadaver feet, from eight males and four females, that had been amputated above the ankle along with a section of leg were studied. Specimens had no evidence of previous injury, operations, osteoarthritis or severe deformity by visual inspection and X-ray. Five were left and seven were right feet. The mean age at the time of death was 32 years (range, 18–45 years). The tibia and fibula were amputated at the junction of the middle and distal thirds. The skin, subcutaneous tissues and muscle were dissected from the most proximal portion. The interosseous and ligaments of the foot and ankle were kept intact. Specimens were stored frozen at –80°C before the experiment and thawed to room temperature at the beginning of the experiment.

Transducer preparation

The super low pressure-sensitive film with a measurement range of 0.5–2.5 MPa (Fuji Film Company, Tokyo, Japan) was used in this study. The film, measuring 0.2 mm in thickness, was sealed with watertight packaging tape to avoid soaking by tissue fluid. Before each test, the pressure-sensitive film was cut to the shape of the articular surface and inserted into the anterior and posterior subtalar articulations. In some cases, a laminar spreader was used to help open the STJ for insertion of a film. Reference markers were placed on the film

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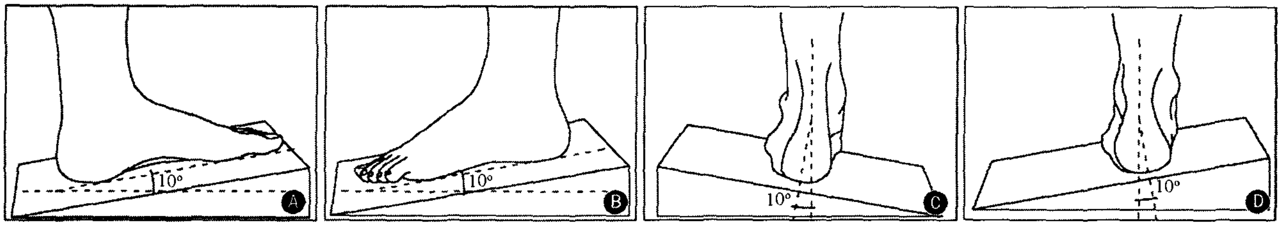

Figure 1. An example of foot supported by a wedge shape foot-specimen positioning jig with angle 10°. **A:** 10° of dorsiflexion; **B:** 10° of plantarflexion; **C:** 10° of eversion; **D:** 10° of inversion.

according to the landmarks chosen on the talus and calcaneus to label the relative position of articular surface.

Specimen loading

Specimens were then mounted onto the load frame of a material testing machine (CSS-44010, Changchun, China) with the foot in a platform or foot-specimen positioning jig. These jigs were designed to hold the specimens in four different anatomical positions with various angles: dorsiflexion, plantarflexion, inversion and eversion (Figure 1). The loading platform and jigs had a high friction surface to prevent anterior-posterior or medial-lateral sliding of the foot. This high-friction surface also gave rise to the generation of shear forces in the system, but the load-cell of the test apparatus did not measure these forces.[9] The tibia was maintained perpendicular to the ground surface and a preset vertical load imposed on the proximal tibia to compress the pressure-sensitive film inserted in the STJ. Each foot was tested under a 600 N load in a neutral position and in different foot positions (serial changes in 5°, 10°, 15° of adduction, abduction, inversion, eversion, plantarflexion and in 5°, 10°, 15°, 20°, 25° and 30° of dorsiflexion). After insertion of the film between the surfaces of the joint, the load on the joint was increased from zero to maximum within 30 seconds. This load was maintained for 15 seconds, after which the load was released and the transducer removed. In the mean time, we verified the loading process according to the preset program and monitored the displacement of the shaft of the tibia through software evaluation (CSS-44010 software version 3.6.16, Figure 2).

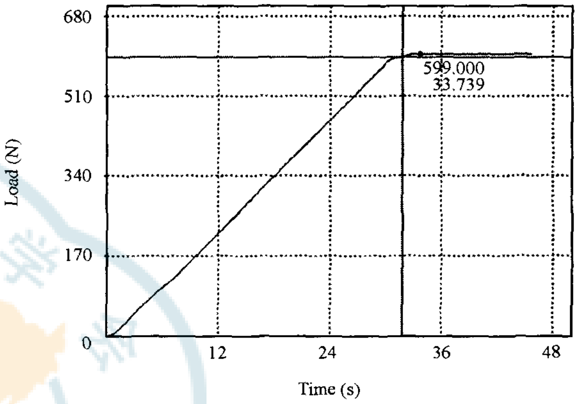

Figure 2. An example of a load-deformation curve (Display of CSS-44010 software version 3.6.16): the 600 N load on the STJ was increased from zero to maximum within 30 seconds. This load was maintained for 15 seconds. The curve was not wave. It illustrated that the displacement of shaft of tibia was tiny.

Transducer analyses

The pressure-sensitive films were imaged within twenty-four hours of testing, along with a set of calibration prints, using a flatbed scanner (Scanjet Plus, Hewlett-Packard, San Jose, USA) at a resolution of 1200×2400 dots per inch (dpi) and 256 gray levels. The coloration area was calculated with image-analysis software (Sigma Scan Pro 5.0, Systat, USA). The total contact area was estimated for the area on which the local pressure was greater than 0.5 MPa.

Statistical analysis

All data were entered into an Excel files, read in SPSS 12.0, and repeated measures analysis of variance (ANOVA) with simple contracts was performed. Results were expressed as mean ± standard deviation (SD) in each group. For all analyses, statistical significance was set at the 0.05 level.

RESULTS

The displacement of the shaft of tibia was less than 2 mm. The contact areas of the anterior and posterior subtalar articular surface diversified according to regular pattern with the foot in various positions (Figure 3). In the ankle-foot neutral position, the contact area of STJ was (2.79±0.24) cm^2. In the motion range of ADD-ABD, the difference of contact areas in different positions were statistically significant (F=221.361, P <0.05, repeated measures ANOVA) and the maximum contact area was (3.00±0.26) cm^2 when the foot was positioned 10° of ABD (Figure 4). In the range of motion of DF-PF, the diversity of the contact areas in different positions had statistical significance (F=121.067, P <0.05, repeated measures ANOVA) and the maximum contact area was (3.61±0.25) cm^2 when foot was positioned 20° of DF (Figure 5). In the range of motion of inversion-eversion (INV-EV), the diversity of contact areas in different position had statistical significance (F=256.252, P <0.05, repeated measures ANOVA) and the maximum contact area was (3.14±0.26) cm^2 when the foot was positioned 10° of EV (Figure 6).

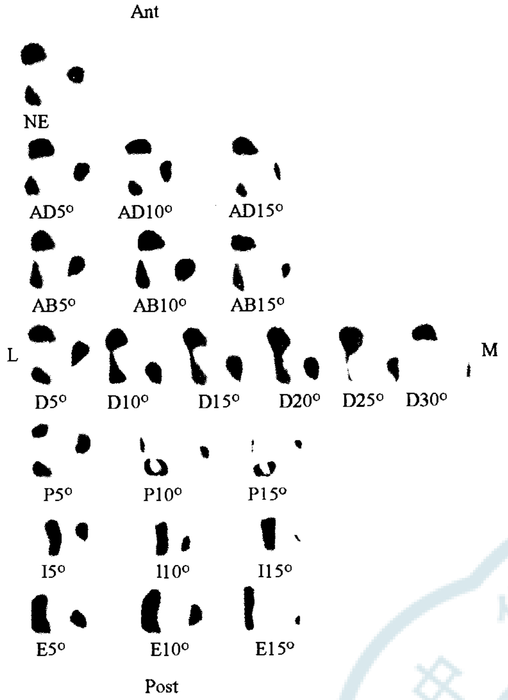

Figure 3. An example of the contact area of STJ in different anatomical positions with various angles: adduction/abduction, dorsiflexion/plantarflexion, inversion/eversion, and foot-ankle neutral. NE: neutral; AD: adduction; AB: abduction; D: dorsiflexion; P: plantarflexion; I: inversion; E: eversion; L: lateral; M: medial; Ant: anterior; Post: posterior.

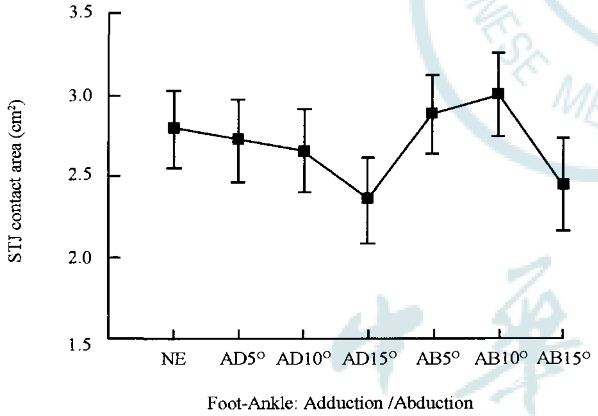

Figure 4. Variation of the STJ contact area with the foot-ankle in various adduction/abduction. Differences in various adduction/abduction were statistically significant (F=221.361, P <0.05, repeated measures ANOVA). Data are plotted as mean ± SD. The maximum contact area showed in AB10° ((3.00±0.26) cm^2). NE: neutral; AD: adduction; AB: abduction.

DISCUSSION

The management of biomechanical misalignment of the lower extremity and the associated pathologic symptoms often involves the use of foot orthotic therapy. Orthotic prescriptions are aimed at placing the foot in such a position as to encourage as near normal foot alignment and function as possible. Plaster casts of the foot are the most frequent method used to prepare positive casts or models of the foot that the orthosis are molded on. Most of the foot orthotic therapy used today involves the foot being casted in a nonweightbearing position, with the STJ held in its neutral position and the midtarsal joint in its maximally pronated position.[10-12]

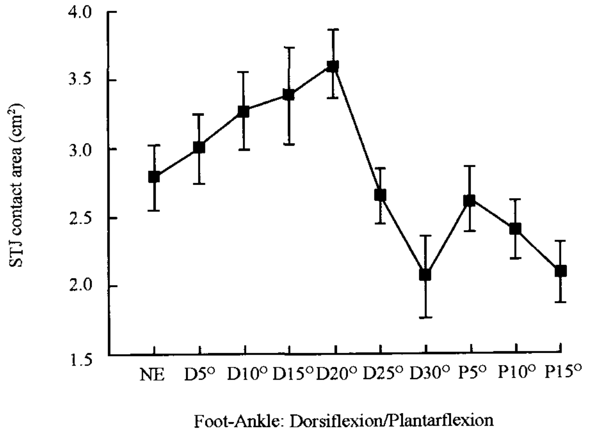

Figure 5. Variation of the STJ contact area with the foot-ankle in various dorsiflexion/plantarflexion. Differences in various dorsiflexion/plantarflexion were statistically significant (F=121.067, P <0.05, repeated measures ANOVA). Data are plotted as mean±SD. The maximum contact area showed in D20° ((3.61±0.25) cm^2). NE: neutral; D: dorsiflexion; P: plantarflexion.

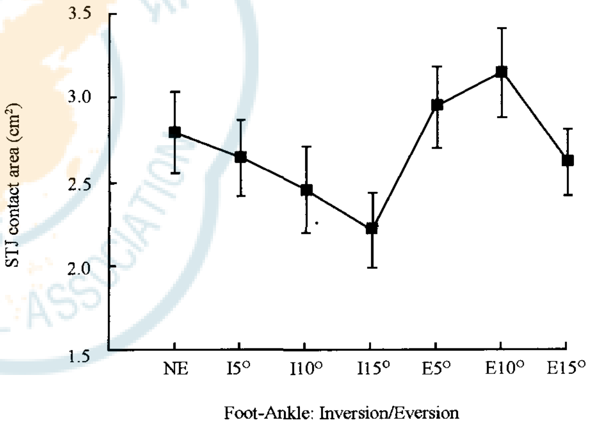

Figure 6. Variation of the STJ contact area with the foot-ankle in various inversion/eversion. Differences in various inversion/eversion were statistically significant (F=256.252, P <0.05, repeated measures ANOVA). Data are plotted as mean±SD. The maximum contact area showed in E10° ((3.14±0.26) cm^2). NE: neutral; I: inversion; E: eversion.

The foot has two major functions: support and propulsion. It behaves as a flexible structure to allow stability on uneven surfaces during the central part of the stance phase and as a rigid structure to support the body in standing or to allow the forefoot to act as a lever in propelling, particularly at toe-off. The STJ plays a key role in converting the foot from one function to the other and a fundamental role in the transmission of loads between the leg and the foot.[13] It has been modeled as a mitered hinge, screw-like, or a multiaxial joint. The rotation of the foot about the longitudinal axis is transmitted to the tibia, imposing rotation on it about its long axis. Various running injuries could be from lack of coordination between subtalar and knee joint actions.[14]

The STJ neutral is the position typically used by clinicians to obtain a cast representation of a patient's foot before fabrication of biomechanical functional orthosis. But no one method for measuring STJ neutral has been proven accurate and reproducible by different testers. In 1977, Root et al published a textbook containing a theory about the STJ neutral position. Root described subtalar joint neutral as the position in which the forefoot is locked on the rearfoot when the midtarsal joint is maximally pronated. Root's theories on biomechanics had been the gold standard for many years. His theories had been used by physicians as the basis for treatment of lower extremity biomechanical problems.[15] Blake et al[16] reported a 78% improvement according to patients using orthosis fabricated from STJ neutral position casts. Moraros et al[17] conducted a prospective study which found that 83% of patients were satisfied with their STJ-neutral-cast orthosis and 95% reported at least partial resolution of their original problem. However, subsequent research has failed to reproduce his original results. Therefore, many current researchers are discarding these ideas and developing new theories about subtalar joint neutral and the biomechanics of the foot during gait. Several different methods exist for taking subtalar joint measurements. Elveru et al[18] reported that STJ neutral is the position the foot will be in when patient is lying in the prone position. The forefoot is passively pronated and the ankle is dorsiflexed. Sell et al[19] reported that the use of an inclinometer, or angle finder, could be used to determine STJ neutral in a weightbearing (closed kinetic chain) position. McPoil et al[6] described a standing method of locating STJ neutral. The medial and lateral aspects of the talar head are palpated for congruence with the navicular. Regardless of these findings, no one accepted method for the measurement of STJ neutral has been proven both accurate and reproducible by different testers. In addition, no researcher has shown why orthosis fabricated from a neutral position cast based on Root's theories can alleviate patient symptoms, given that thousands of patients have claimed relief from what has been a universally accepted practice among podiatric and other physicians.

In 2002, International Society of Biomechanics (ISB) reported definition of the neutral configuration of the ankle joint complex. It is zero degrees between the long axis of the tibia/fibula and the line perpendicular to the plantar aspect of the foot projected onto the sagittal plane of the tibia/fibula, zero degrees between the long axis of the tibia/fibula and the line perpendicular to the plantar aspect of the foot and zero degrees between the line perpendicular to the frontal plane of the tibia/fibula and the long axis of the second metatarsal, projected onto the transverse plane of the tibia/fibula.[20] But single joint neutral can be defined as the position where the concave and convex surfaces are completely congruous. Joints such as STJ, therefore, are not necessarily in neutral position when the foot is placed in the traditional concept of neutral position.

An optimal ankle model and an appropriate biomechanical loading method are of vital importance in the basic researches of ankle surgery. There are three classical anatomic foot axes, i.e. coronal axis, vertical axis and sagittal axis, according to which we defined six elementary motions as DF, PF, ADD, ABD, INV and EV. Physiologically these motions are often combinations of two or three motions. For example, ADD, INV, and PF are combined to produce pronation; on the other hand, combining ABD, EV and DF are referred to as supination. The foot is so special in its motions and complicated in anatomy that it has always been difficult to build a biomechanical model with maximum physiological similarity to a cadaveric foot specimen. In our study, the contact areas of the STJ were assayed by dynamic axial loading and monitoring of a tibia shaft in the neutral position and other elementary directions in closed kinetic chain movements, during which no displacement of more than 2 mm were permitted for tibia shaft, foot or ankle. Each motion was graded by a 5° increase toward the directions of foot movements. In the early days of our study, data showed that the STJ contact area increased in DF, ABD and EV but decreased in PF, ADD and INV.[21] We also found that the contact area began to decrease and became less than its counterpart in the neutral position when the foot was positioned 25° of DF, 15° of ABD and 15° of EV. Based on these findings, we selectively measured the contact area in different foot positions of these angles. Our data exhibited that the maximum STJ contact areas, which were all larger than those measured in the classical neutral position, were achieved in 10° of ABD during foot ADD-ABD, 20° of DF during foot DF-PF and 10° of EV during foot INV-EV, respectively. According to definition of single joint neutral, that the maximum STJ contact areas were achieved when the STJ neutral position was obtained, we assumed that the most approximate STJ neutral position was in the foot position of 10° of ABD, 20° of DF and 10° of EV. As combined ABD, DF and EV were referred to as extorsion or pronation, this concept of the STJ neutral position was quite similar to that reported by Root theories.[15]

Currently, there are many published reports about minimally invasive surgery. It is therefore important for clinicians to note noninvasive procedures. For example, plaster casting is much more widely used in orthopedics than surgical procedures. Even after perfect surgical procedures, the plaster castings are still often used to help recovery. The plaster castings of lower extremities with fabrication of approximation physiological functions can not only help a patient's early recovery, but also can reduce complications. Regarding the current debate on STJ neutral, the author hopes this study can provide some reference value to obtain a more optimal plaster casting before fabrication of biomechanical functional orthosis by clinicians. A clinical research project following this study will be carried out in our future study.

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