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ANKLE LIGAMENT STRAIN DURING SUPINATION SPRAIN INJURY – A COMPUTATIONAL BIOMECHANICS STUDY

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This study presents ankle ligament strain data during a grade I mild anterior talofibular ligamentous sprain. Kinematics data obtained during the injury and a 3BW were imported to a validated dynamic foot model. Four simulations were done: (1) inversion, (2) inversion plus plantarflexion, (3) inversion plus internal rotation, and (4) inversion, plantarflexion and internal rotation. Results showed that in situation (1), the calcaneofibular ligament was strained the most (12%), followed by the anterior talofibular ligament (10%). In situations (2) and (3), both ligaments were strained to about 14-16%. In situation (4), the anterior talofibular ligament was strained to 20%. This study suggested that plantarflexion and internal rotation, together with inversion, may have greatly strained and torn the anterior talofibular ligament during the reported injury event.

KEY WORDS: injury mechanism, injury aetiology, ankle inversion sprain.

INTRODUCTION: Ankle sprain is a common sports trauma (Fong et al, 2007). A suggested mechanism is excessive ankle joint supination, which accounts for over 80% of all ankle sprain injuries. This mechanism has been widely presented in the literature clinically and qualitatively as a combination of inversion and plantarflexion. A recent first ever biomechanics quantitative investigation on a real accidental supination ankle sprain injury event revealed that internal rotation also occurred in such an injury (Fong et al, 2009b). The injury was diagnosed as a grade I mild anterior talofibular ligamentous sprain immediately, and was presented with the kinematics as captured by three video cameras, plus the plantar pressure data as captured by a pair of pressure insoles.
In normal landing, the ground reaction force vector is close to the ankle joint centre, so the short moment arm results in a small ankle twisting torque which could be accommodated by the muscles and ligaments. An ankle sprain is probably caused by the deviation of such ground reaction force vector from the ankle joint centre, usually at the lateral plantar edge acting to the medial aspect during a sideway cutting movement, resulting in a large moment arm and thus an explosive ankle supination torque (Fong et al, 2009a). Such torque would trigger very fast joint twisting motion and stretch the lateral ligaments in a vigorous way.
Information on the ankle ligament strain during the injury may help a better understanding of the injury aetiology and mechanism. This computational biomechanics study presents the ankle ligament strains during this real accidental injury event. Four simulations were conducted to show the effect of different combinations of joint orientation on the strain in various ligaments. Since the injury was diagnosed as a grade I mild anterior talofibular ligamentous sprain, a high strain in this lateral ligament was expected.

METHODS: A three-dimensional multi-body dynamic foot model was used in this study (Wei et al, 2011). The model has been validated for studying ankle injury by a human cadaveric

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biomechanics study (Wei et al, 2010). Joint anatomical features were taken from computer tomography (CT) images. Detailed features of the foot/ankle complex were obtained by importing Digital Imaging and Communications in Medicine (DICOM) files from an individual CT scan into Materialise's Interactive Medical Imaging Control System (MIMICS) (Materialise, Ann Arbor, MI). This yielded a three-dimensional surface model of the bones as Stereolithography (STL) files for export. To reduce the size of the surface files and subsequent model, the STL files were re-meshed in MIMICS to smooth the surface of each bone. Exported files were then imported into the three-dimensional solid modelling software SolidWorks (TriMech Solutions, LLC, Columbia, MD) as Mesh Files. SolidWorks along with the ScanTo3D package was used to further construct each bone and simplify the bone surfaces. SolidWorks Motion was then used to assemble bones, obtain proper positioning, add necessary components, and run simulations. The tibia was fixed in space, the fibula, talus, and calcaneus were free to move, and the rest of the bones were fused together and moved as a rigid body. Twenty ligaments were included and represented as linear spring elements (Figure 1), with stiffness values from the literature. A model sensitivity analysis was conducted to ensure that moderate ligament stiffness variations did not significantly alter conclusions drawn from the model.

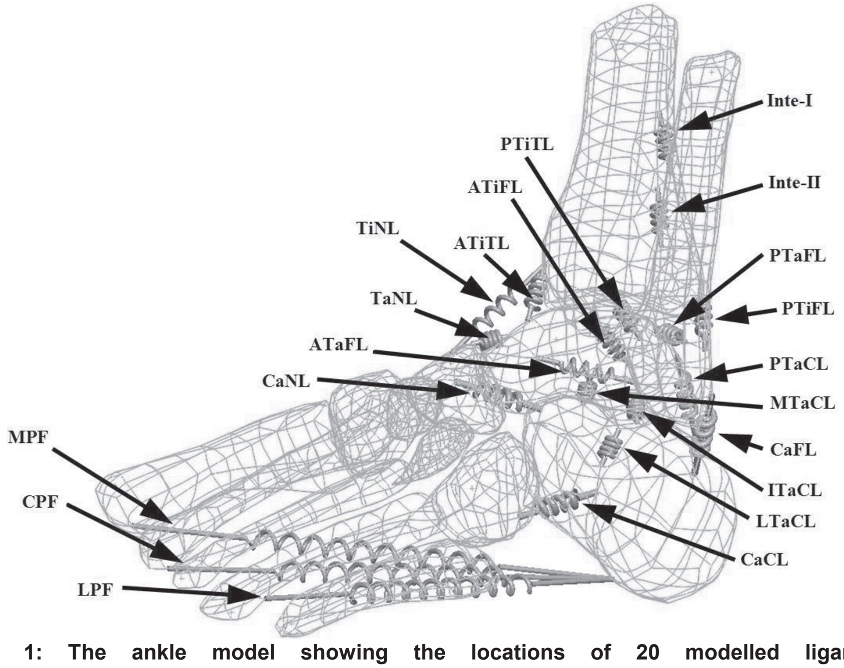

Figure 1: The ankle model showing the locations of 20 modelled ligaments. (Full abbreviation details and stiffness of each ligament available from Wei et al, 2011).

To simulate the said injury event, approximately three times body load (1840 N) was applied to the proximal end of the model, proportionally distributing it between the tibia and the fibula with one-sixth of the loading in the fibula. The case report documented a maximum 48° ankle inversion, 20° plantarflexion and 30° internal rotation during the injury event. To systematically investigate the contribution of these planar motions to the injury, four scenarios were examined: (1) 48° inversion with an axis of rotation passing through the calcaneus antero-posteriorly (Figure 2b); (2) 48° inversion plus 20° plantarflexion with an axis of rotation passing through the talus medial-laterally (Figure 2c); (3) 48° inversion plus 30° internal rotation with an axis of rotation along the tibia and passing through the talus (Figure 2d); and (4) a combined 48° inversion, 20° plantarflexion and 30° internal rotation (Figure 2e).

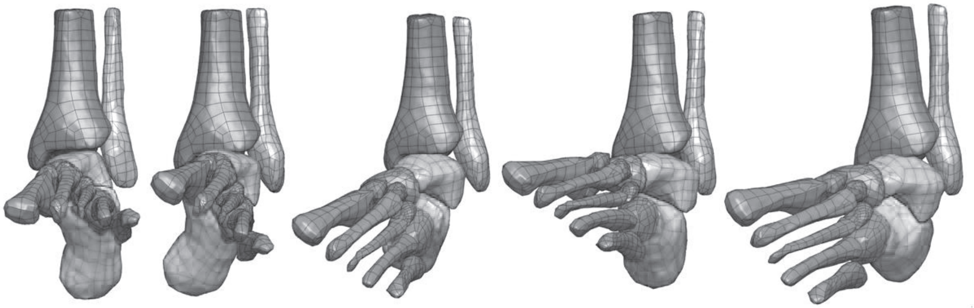

Figure 2: Anterior views of the ankle model in (a) neutral position; (b) 48° inversion; (c) inversion plus 20° plantarflexion; (d) inversion plus 30° internal rotation, and (e) combined inversion, plantarflexion and internal rotation.

Ligament strains were determined and were presented in percentage (%), which was the relative elongation of the ligament. Only ligaments being strained 2% or more were presented in this report.

RESULTS: Figure 3 showed the strains of selected ligaments for the four motion scenarios. For scenario 1, the calcaneofibular ligament (CaFL) was strained the most at 12%, and the anterior talofibular ligament (ATaFL) and the lateral talocalcaneal ligament were strained to about 10%. In scenario 2 and 3 where 20° plantarflexion or 30° internal rotation was added, both CaFL and ATaFL were strained to 14-16%. In scenario 4 with a combined 48° inversion, 20° plantarflexion and 30° internal rotation, the ATaFL was strained the most at 20%, followed by CaFL which was strained to 16%.

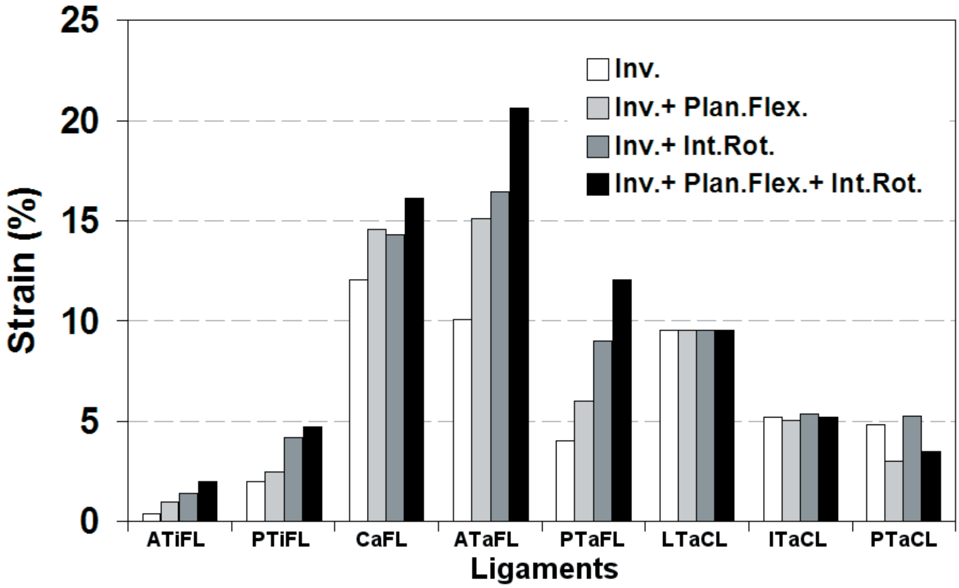

Figure 3: Strains in various selected ligaments for different ankle motions. (ATiFL: anterior tibiofibular; PTiFL: posterior tibiofibular; CaFL: calcaneofibular; ATaFL: anterior talofibular; PTaFL: posterior talofibular; LTaCL: lateral talocalcaneal; ITaCL: interosseous talocalcaneal; PTaCL: posterior talocalcaneal.)

DISCUSSION: The injury event was a grade I mild anterior talofibular ligament sprain, which is characterized as minimum tearing of ligament fibers (Noyes et al, 1989). Previous studies reported that failure strain of ankle ligaments is in the range of 30-35% (Funk et al, 2000), and ligament collagen fibers start to tear when half of the failure strain is reached (Yahia et al, 1990). The ATaFL ligament strain in this presented grade I sprain case reached 15-20% strain, which is about half of the suggested failure strain. Therefore we believe that the reported ankle supination sprain case was caused by excessive strain in the anterior talofibular ligament.

This study also showed that plantarflexion and internal rotation both play important roles in an ankle supination injury. The highest strain seen in the anterior talofibular ligament with a combined inversion, plantarflexion and internal rotation is in concert with the injury biomechanics documented in the accidental ankle injury incident (Fong et al, 2009b). While clinically the ankle supination sprain injury mechanism has been typically presented as a combination of inversion and plantarflexion, this study revealed the importance of the internal rotation component as it raised the strain to 20%, which is thought to induce collagen fiber tears in the anterior talofibular ligament. We wish that this study could raise a debate on ankle joint orientation during a supination sprain injury, and could inspire sports biomechanists to design proper intervention to prevent the injury.

CONCLUSION: This study showed a high strain in the anterior talofibular ligament during an accidental injury event in the laboratory which caused a grade I mild anterior talofibular ligamentous sprain. The results suggest that both plantarflexion and internal rotation, together with inversion, would greatly raise the strain and injure the anterior talofibular ligament.

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