Kinematics Analysis of Ankle Inversion Ligamentous Sprain Injuries in Sports

Five Cases From Televised Tennis Competitions

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Background: Ankle ligamentous sprain is common in sports. The most direct way to study the mechanism quantitatively is to study real injury cases; however, it is unethical and impractical to produce an injury in the laboratory. A recently developed, model-based image-matching motion analysis technique allows quantitative analysis of real injury incidents captured in televised events and gives important knowledge for the development of injury prevention protocols and equipment. To date, there have been only 4 reported cases, and there is a need to conduct more studies for a better understanding of the mechanism of ankle ligamentous sprain injury.

Purpose: This study presents 5 cases in tennis and a comparison with 4 previous cases for a better understanding of the mechanism of ankle ligamentous sprain injury.

Study Design: Case series; level of evidence, 4.

Methods: Five sets of videos showing ankle sprain injuries in televised tennis competition with 2 camera views were collected. The videos were transformed, synchronized, and rendered to a 3-dimensional animation software. The dimensions of the tennis court in each case were obtained to build a virtual environment, and a skeleton model scaled to the injured athlete’s height was used for the skeleton matching. Foot strike was determined visually, and the profiles of the ankle joint kinematics were individually presented.

Results: There was a pattern of sudden inversion and internal rotation at the ankle joint, with the peak values ranging from 48°-126° and 35°-99°, respectively. In the sagittal plane, the ankle joint fluctuated between plantar flexion and dorsiflexion within the first 0.50 seconds after foot strike. The peak inversion velocity ranged from 509 to 1488 deg/sec.

Conclusion: Internal rotation at the ankle joint could be one of the causes of ankle inversion sprain injury, with a slightly inverted ankle joint orientation at landing as the inciting event. To prevent the foot from rolling over the edge to cause a sprain injury, tennis players who do lots of sideward cutting motions should try to land with a neutral ankle orientation and keep the center of pressure from shifting laterally.

Keywords: injury biomechanics; injury mechanism; sports trauma; ankle supination injury

Ankle ligamentous sprain is the most common injury in sports, and the majority clinically and qualitatively present with an inversion or supination mechanism. Understanding the injury mechanism, preferably with biomechanics quantities, is a key component required for the development of injury prevention protocols and the design of protective equipment. With the advance of sport biomechanics technique, numerous approaches have emerged for the quantitative understanding of injury mechanism. Among different methods, the most direct way is to investigate real injury incidents; however, it is unethical and practically impossible to perform experiments in which test subjects are purposefully injured. In rare cases, accidents have unexpectedly occurred in a biomechanics laboratory with calibrated motion analysis equipment. Recently, there were 2 such reports on ankle inversion sprain injury with reported kinematics data. In each study, the subject participated in a biomechanics test with a sideward cutting motion and accidentally sustained an inversion ankle sprain injury.

There are far more real injury incidents unintentionally captured during televised sports events than in the biomechanics laboratory; however, the environments of the sports venues are less calibrated or even not calibrated. The first ever real injury analysis during a sports event was published in 1977, which reported a human patellar...
tendon rupture captured unintentionally during a weight-lifting competition. There was a calibrated camera capturing the sagittal plane motion of the athlete at 50 frames per second, and together with another age-, body mass-, and height-matched experienced weightlifter performing the motion again in a laboratory environment, the resultant knee joint moment at the time of tendon rupture was mathematically determined. The well-aligned camera and the consistent weightlifting performance as demonstrated by another experienced weightlifter made the analysis possible. On many other occasions, injury motions were captured during unanticipated moves and in an uncalibrated environment with panning cameras. To cope with this limitation, Krosshaug and Bahr developed a model-based image-matching (MBIM) motion analysis technique to analyze 3-dimensional human motion from uncalibrated video sequences and successfully used the method to analyze knee joint ligamentous injury in sports.14,15

The technique was recently further developed to investigate ankle joint motion,16 and it was employed to investigate 2 cases during the 2008 Beijing Olympics.17 This study presents 5 cases in tennis and a comparison with 3 previous studies for a better understanding of the mechanism of ankle ligamentous sprain injury.

METHOD

An online video search was performed. To be included in the analysis, a video must have at least 2 camera views showing the shank, the ankle joint, and the foot segment during the injury motion. An injury motion was defined as when the athlete (1) performed an unwanted excessive ankle inversion during a landing and sideward cutting motion, with the foot segment rolling over the lateral edge of the foot; (2) needed to withdraw from the game or to continue after a brief rest with treatment to the ankle joint; and (3) was reported to have sustained an ankle sprain injury in the post-match report. Five injury cases in various televised tennis competitions are presented in this study (Table 1). The university ethics committee approved the study.

Model-Based Image-Matching Motion Analysis

Details of the MBIM motion analysis were reported previously.16 The videos were transformed into uncompressed AVI image sequence with Premiere Pro, de-interlaced with

![Figure 1. Left column: screenshots from 1 view showing the moment with the greatest ankle inversion. Other columns: the ankle joint orientation presented in the inversion/eversion, plantar flexion/dorsiflexion, and internal/external rotation planes. Note that mirrored images of the injured right ankles in Cases 2 and 4 are presented for comparison with the injured left ankles in the other 3 cases.](http://ajs.sagepub.com/supplemental)
Provo, Utah) scaled to the injured athlete’s height was used for the skeleton matching, first on the shank segment and then the foot and toe segments. The matching of the virtual tennis court environment and the skeleton model was done simultaneously, frame by frame. The matched video sequences and skeleton models for all 5 cases are available online at http://ajs.sagepub.com/supplemental/.

The foot strike was determined visually from the video sequence. The profile of the ankle joint orientation was then read into a self-compiled script (Matlab, MathWords Inc, Natick, Massachusetts) for calculating the joint kinematics by the joint coordinate system method. The ankle joint kinematics of each case was presented at video frame frequency until at most 0.50 second after foot strike if data are

![Diagram of joint orientation and angular velocity](image-url)
available, and was presented individually but not after averaging all 5 cases, as we expected great variations and perhaps different trends across the different cases. The data were presented in accordance to the recommendation of the International Society of Biomechanics, and they were filtered and interpolated by Woltring’s generalized cross-validation spline package with 15 Hz cutoff frequency.

RESULTS

Figure 1 shows the moment with the greatest ankle inversion in each case from 1 view, and the matched skeleton model in 3 planes for visual comparison. Figure 2 shows the profile of ankle kinematics, whereas Table 2 shows the peak angle, velocity, time to peak angle, and the comparison with the cases reported in 3 previous studies. Great variations in the peak inversion and peak internal rotation were observed in the 5 injury cases, which reached 48°-126° and 26°-99°, respectively. Nevertheless, there was still a pattern of sudden inversion and internal rotation at the ankle joint, but a fluctuation around the neutral position for plantarflexion and dorsiflexion within the first 0.50 seconds after foot strike. The peak inversion velocity of the 5 cases in this study ranged from 509 to 1488 deg/sec.

DISCUSSION

The results of this study are in agreement with those of previous studies, which suggested that plantar flexion is absent but internal rotation is present at the time of peak ankle inversion during the injuring motion. Case 2 showed the same peak inversion but a smaller peak inversion velocity than the case presented by Fong and colleagues, but a larger peak internal rotation and a larger internal rotation at the time of peak inversion, which were about 25° and 26°, respectively. The case presented by Kristianslund and colleagues also showed a small inversion of about 35°, but a larger internal rotation of 55°. These findings suggested that the previously suggested clinical qualitative injury mechanism, which was supination, or a talocrural joint plantar flexion with the subtalar joint adducting and inverting, may not be the only possible mechanism to cause an ankle inversion sprain injury. When one sustains an ankle sprain injury while landing from a jump, the ankle joint is likely to be plantarflexed before landing, and therefore a combined inversion plus plantar flexion might be the injury mechanism. In tennis, there are more horizontal side-ward movements in medial and lateral directions, but fewer vertical jump-landing motions, which may happen more frequently in basketball and volleyball. Therefore, in tennis, instead of plantar flexion, internal rotation could also be one of the causes of ankle inversion sprain injury, especially for a planted foot on the sports ground that could not be further plantarflexed into the ground. Further similar studies should be conducted in other sports, as the nature of different sport events would not be the same.

There are cadaveric studies in the literature suggesting the effect of different ankle joint orientations and loads on the anterior talofibular ligament. In 1988, Renstrom and coworkers found that when the ankle joint changed from 10° of dorsiflexion to 40° of plantar flexion, the strain of the anterior talofibular ligament increased by 3.3%. There was no increase during internal rotation, but a 1.9% decrease in external rotation. In 1998, Bahr and coworkers found the largest increase in force in the anterior talofibular ligament when the ankle joint was supinated and plantarflexed with a 76-N compressive load. On the basis of these results, these investigators suggested that the anterior talofibular ligament is a primary restraint in inversion, where injuries typically occur in combined plantar flexion, supination, and internal rotation. In a recent study, Ringleb and coworkers reported that when the anterior talofibular ligament was sectioned, the maximum ankle joint motion increased in inversion (6.9° to 11.2°), internal rotation (6.1° to 14.9°), and internal rotation component during supination (14.8° to 23.0°), but not in
inversion component during supination. The findings from these studies suggested that the anterior talofibular ligament would tighten in plantar flexion, as well as internal rotation. Therefore, excessive and explosive plantar flexion or internal rotation on an inverted ankle joint would cause stress and may rupture the anterior talofibular ligament.

In all cases but case 5, the peak inversion was achieved explosively in a very short time after foot strike (0.09-0.17 seconds). The peak inversion velocity of the 5 cases in this study ranged from 509 to 1488 deg/sec, which was comparable with the data reported in the previous studies, which ranged from 632 to 1752 deg/sec. Another similarity was that they all presented with a slightly inverted ankle joint at the time of foot strike, which is a vulnerable joint orientation to cause the injury. There were also numerous studies in subjects with chronic ankle instability that showed an increased ankle inversion as the cause of the sprain injury. Another recent study also suggested that patients with chronic ankle instability demonstrated a laterally shifted center of pressure during running. We believe that such a shifted center of pressure would indicate a slightly inverted ankle joint, which could have incited the ankle sprain injuries in this study. For case 5, the ankle joint was at a neutral orientation at the foot strike, however it gradually increased to around 15° inversion after 0.1 seconds, to 50° of inversion after 0.3 seconds, and to as much as 130° of inversion after 0.5 seconds. We believe that the patient had undergone a preinjury phase during this 0.1 seconds as compared with the case presented by Fong and colleagues. The progression of the plantar pressure might have gone wrong, probably by shifting to the lateral side, thus causing the foot to roll over the lateral edge and bring about the injury.

There is also a limitation in that we could not tell whether the excessive inversion and internal rotation were the cause or the consequence of the ankle sprain injury. Therefore, it may be more sensible to interpret the velocity of the motion instead of just the range of the motion. One may also suggest that the velocity of the motion at the initial contact would be the critical parameter. However, in an earlier case report, a biphasic pattern was observed, with a preinjury phase happening from 0.06 to 0.11 seconds and the injury phase from 0.11 seconds onward after the initial contact, as suggested after observing the deviation of plantar pressure excursion path. Since we expect that there would often be great variation among different injury incidents, we presented the profile of each single case, but not the overall mean profile among the 5 cases. The peak inversion velocities varied among a wide range, but they were in general higher than the 2 accidental injury cases in the laboratory environment (632 and 559 deg/sec), and lower than the 2 cases that happened during real competitions (1752 and 1397 deg/sec).

CONCLUSION

Analysis of the 5 ankle inversion ligamentous sprain cases in this study suggests that large and sudden inversion and internal rotation but not plantar flexion had happened. Internal rotation could be one of the causes of ankle inversion sprain injury. The slightly inverted ankle orientation on landing could be an inciting event. We recommend tennis players who do lots of sideward cutting motions to try their best to land with a neutral ankle orientation and to keep their center of plantar pressure from shifting to the lateral aspect, in order to prevent the foot from rolling over the edge to cause an ankle inversion sprain injury.

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REFERENCES


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