Title: Kinematics analysis of ankle inversion ligamentous sprain injuries in sports - five cases from televised tennis competitions

What is known about the subject

Video analysis of real injury incidents gives valuable information for the understanding of injury mechanism. For ankle inversion sprain injury, 4 quantitative case reports have been reported from 3 recent articles,[10,12,17] suggesting the importance of ankle joint internal rotation as one of the causes to incite an ankle inversion injury. However the available data is still too little to draw a more representative conclusion.

Adds to existing knowledge

This paper reveals the kinematics of ankle inversion ligamentous sprain of five cases from televised tennis competitions. The results are in agreement with previous reports, suggesting that internal rotation is a key component of the injury mechanism of lateral ankle joint sprain. It also suggests that an inverted ankle orientation at landing could be an inciting event.

INTRODUCTION

Ankle ligamentous sprain is the most common injury in sports, with the majority having an inversion or supination mechanism presented clinically and qualitatively.[9] 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.[2] With the advance of sport biomechanics technique, numerous approaches have emerged for the quantitative understanding of injury mechanism.[13] Among different methods, the most direct way is to investigate real injury incidents, however, it is unethical and practically impossible to perform experiments where test subjects are purposefully injured. In rare cases, accidents occurred unexpectedly in a biomechanics laboratory with calibrated motion analysis equipment. There were two recent such reports on ankle inversion sprain injury with reported kinematics data.[10,12] 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 captured unintentionally on televised sports events than in biomechanics laboratory, however, the environments of the sports venues are less 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.[25] 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 weight-lifter performing the motion again in a laboratory environment, the resultant knee joint moment at the time of tendon rupture was determined mathematically. The well-aligned camera and the consistent weight-lifting performance as demonstrated by another experienced weight-lifter made the analysis possible. In many other occasions, injury motions were captured during unanticipated moves and under un-calibrated environment with panning cameras. To cope with this, Krosshaug and Bahr[14] developed a model-based image-matching (MBIM) motion analysis technique to analyse three-dimensional human motion from un-calibrated video sequences, and successfully utilized the method to analyse knee joint ligamentous injury in sports.[15]

The technique was recently further developed to investigate ankle joint motion,[16] and was employed to investigate two cases during the 2008 Beijing Olympics.[17] This study presented five cases in tennis and a comparison with three 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, (3) was reported to have sustained the ankle sprain injury from the post-match report. Five injury cases in various televised tennis competitions were presented in this study (Table 1). Invitation letters were sent to the address of each injured athlete's home, tennis club or association, and fans club to seek for informed consent, medical diagnosis and other information of the injury incident, but none of the five injured athletes replied. The university ethics committee approved the study, and the identities of the athletes have to be hidden for the sake of patient privacy

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 Photoshop, and then synchronized and rendered into 1Hz video sequences by After-Effects (Adobe CS4, Adobe Systems Inc, San Jose, California, US). The video sequences were then matched by 3D animation software (Poser 4 & Poser Pro Pack, Curious Labs Inc, Santa Cruz, California, US). The dimensions of the tennis court in each case were obtained from International Tennis Federation to build a virtual environment. A skeleton model (Zygote Media Group Inc, Provo, Utah, US) scaled to the injured athlete's height was used for the skeleton matching, firstly 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 sequence and the skeleton model 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, US) for calculating the joint kinematics by the joint coordinate system method.[11] The ankle joint kinematics of each case was presented at video frame frequency until at most 0.50 second after foot strike if data is available, and was presented individually but not after averaging all five 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,[24] and were filtered and interpolated by Woltring's generalized cross-validation spline package with 15Hz cut-off frequency.[23]

RESULTS

Figure 1 showed the moment with the greatest ankle inversion in each case from one view, and the matched skeleton model in 3 planes for visual comparison. Figure 2 showed the profile of ankle kinematics, while Table 2 showed the peak angle, velocity, time to peak angle, and the comparison with the cases reported in three previous studies. Great variations of the peak inversion and peak internal rotation were observed in the 5 injury cases, which reached 48-126 degrees and 35-99 degrees respectively. Nevertheless, there was still a trend 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 second after foot strike. The peak inversion velocity of the 5 cases in this study ranged from 509 to 1488 deg/s, which were comparable to the data reported in the previous studies which ranged from 632 to 1752 deg/s.[10,12,17]

DISCUSSION

The result of this study is in agreement with previous studies which suggested that plantarflexion is absent but internal rotation is present at the time of peak ankle inversion during the injuring motion.[10,12,17] Case 2 showed the same peak inversion but a smaller peak inversion velocity to the case presented by Fong and colleagues,[10] but a larger peak internal rotation and a larger internal rotation at the time of peak inversion, which were about 25-26 degrees respectively. The case presented by Kristianslund and colleagues[12] also showed a small inversion of about 35 degrees, but a larger internal rotation of 55 degrees. These findings suggested that the previously suggested clinical qualitative injury mechanism, which was supination, or a talocrural joint plantarflexion with the sub-talar joint adducting and inverting[22], may not be the only possible mechanism to cause an ankle inversion sprain injury. When one sustains an ankle sprain injury whilst landing from a jump, the ankle joint is likely to be plantarflexed prior to landing, and therefore a combined inversion plus plantarflexion might be the injury mechanism. In tennis, there are more horizontal sideward 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 plantarflexion, internal rotation could also be one of the causes of ankle inversion sprain injury, especially for a planted foot on the sports ground which could not further plantarflexed into the ground. Further similar studies should be conducted in other sports as the nature of different sport event would not be the same.

There were 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[20] found that when the ankle joint changed from 10 degree dorsiflexion to 40 degree plantarflexion, 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[3] found the largest increase in force in anterior talifibular ligament when the ankle joint was supinated and plantarflexed with a 76N compressive load. Based on the results, they suggested that the anterior talofibular ligament is a primary restraint in inversion, where injuries typically occur in combined plantarflexion, supination and internal rotation. In a recent study, Ringleb and coworkers[21] reported that when the anterior talofibular ligament was sectioned, the maximum ankle joint motion has increased in inversion (6.9 to 11.2 degrees), internal rotation (6.1 to 14.9 degrees), internal rotation component during supination (14.8 to 23.0 degrees), but not in inversion component during supination. The findings from these studies suggested that the anterior talofibular ligament would tighten in plantarflexion, as well as internal rotation. Therefore, excessive and explosive plantarflexion 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 (0.09-0.17s). Another similarity was that they all presented with a slightly inverted ankle joint (10-24 degrees) at the time of foot strike, which is a vulnerable joint orientation to cause the injury.[1] There were also numerous studies in subjects with chronic ankle instability showing an increased ankle inversion as the cause of the sprain injury.[4-8,18] Another recent study also suggested that patients with chronic ankle instability demonstrated a laterally shifted centre of pressure during running.[19] We believe that such a shifted centre 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 ultimately increased gradually to around 15 degrees after 0.1s, to 50 degrees after 0.3s, and as much as 130 degrees after 0.5s. We believe that the patient had undergone a pre-injury phase during this 0.1s as compared to the case presented by Fong and colleagues[10]. 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 incited the injury.

There is also a limitation as we could not tell if 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[10], a biphasic pattern was observed, with a pre-injury 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 a great variation among different injury incidents, we presented the profile of each single case but not the overall mean profile among the five cases. The peak inversion velocities varied among a wide range, but they were in general higher than the 2 accidental injury cases in laboratory environment (632 and 559 deg/s),[10,12] and lower than the 2 cases happened during real competitions (1752 and 1397 deg/s) .[17]

CONCLUSION

The five ankle inversion ligamentous sprain cases in this study suggested that large and sudden inversion and internal rotation but not plantarflexion had happened. Internal rotation could be one of the causes of ankle inversion sprain injury. The slightly inverted ankle orientation at 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 centre 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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FIGURES LEGEND

Figure 1. Left column: Screenshots from one view showing the moment with the greatest ankle inversion; Other columns: The ankle joint orientation presented in the inversion/everion, plantarflexion/dorsiflexion and internal/external rotation planes. Note that mirrored images of the injured right ankles in Case 2 and 4 were presented for comparison with the injured left ankles in the other three cases.

Figure 2. Profile of joint orientation and angular velocity of ankle inversion, internal rotation and plantarflexion in each injury incident.

TABLE

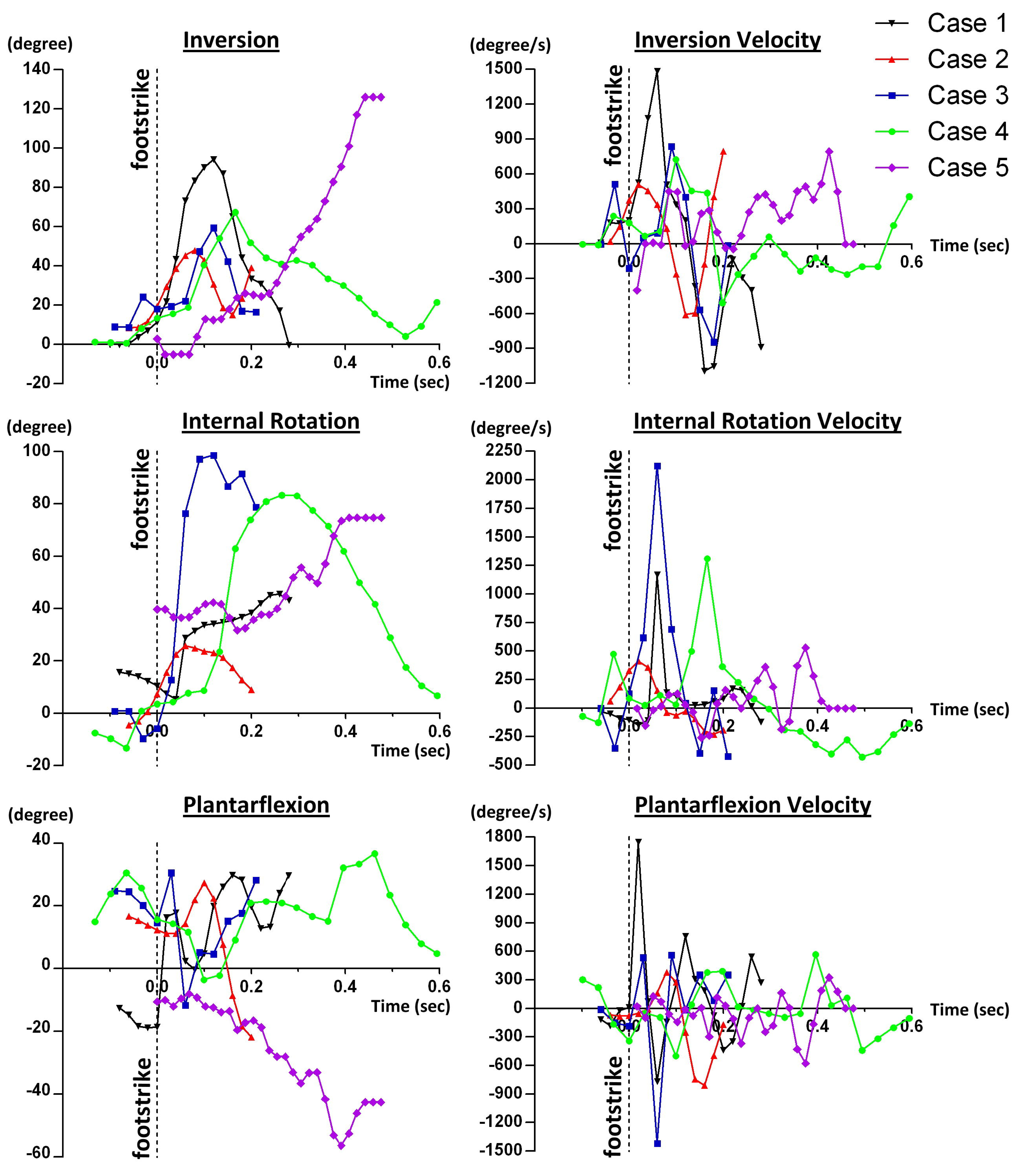
Table 1: Demographics of the five injury incidents in various tennis competitions in this study

Case	Event	Gender	Injured limb	Camera views	Video frequency	Video resolution
1	Vienna 1995	Male	Left	2	50Hz	320 x 240
2	Monte Carlo Open, 1995	Male	Right	2	25Hz	480 x 360
3	German Open 2000, Berlin	Female	Left	2	30Hz	640 x 480
4	Australian Open 2009, Melbourne	Female	Right	2	30Hz	416 x 320
5	WTA Charleston Family Circle Cup, 2010	Female	Left	2	25Hz	400 x 300

Table 2: Peak value of the ankle angles and velocities in each injury incident

	This study					Fong et al 2009	Mok et al 2011		Kristianslund et al 2011
	Case 1	Case 2	Case 3	Case 4	Case 5		Case 1	Case 2	
Peak inversion	94°	48°	59°	67°	126°	48°	142°	78°	~35°
Peak inversion velocity	1488°/s	509°/s	837°/s	724°/s	800°/s	632°/s	1752°/s	1397°/s	559°/s
Time of peak inversion	0.12s	0.08s	0.12s	0.17	0.44s	0.20s	0.08s	0.08s	~0.18s
Peak plantarflexion	30°	28°	31°	37°	-8°	1°	~52°	~16°	~20°
Peak plantarflexion velocity	1748°/s	381°/s	561°/s	571°/s	325°/s	370°/s	N/A	N/A	N/A
Time of peak plantarflexion	0.16s	0.10s	0.03s	0.46s	0.07s	0.04s	0.18s	0.17s	0.30s
Peak internal rotation	46°	26°	99°	84°	75°	10°	~50°	~45°	~55°
Peak internal rotation velocity	1170°/s	412°/s	2124°/s	1312°/s	530°/s	271°/s	N/A	N/A	N/A
Time of peak internal rotation	0.26s	0.06s	0.12s	0.26s	0.41s	0.20s	0.15s	0.12s	0.16s


Video image with matched skeleton
Inversion / eversion
Plantarflexion / dorsiflexion
Internal / external rotation
Case 1
94°
20°
34°
Case 2
48°
22°
48°
Case 3
59°
5°
99°
Case 4
67°
9°
63°
Case 5
126°
42°
75°


Case 1
Case 2
Case 3
Case 4
Case 5
Inversion
(degree)
footstrike
Time (sec)
Inversion Velocity
(degree/s)
Internal Rotation
Internal Rotation Velocity
Plantarflexion
Plantarflexion Velocity