KINEMATICS ANALYSIS OF FIVE ANKLE INVERSION LIGAMENTOUS SPRAIN INJURY CASES IN TENNIS

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Ankle sprain injury is very common in sport and this study investigated its kinematics. Five injury incidents captured in televised tennis competitions were analysed by a model-based image-matching motion analysis technique. Results showed a trend of sudden ankle inversion and internal rotation but not plantarflexion. The peak inversion was achieved explosively in a very short time, which is within 0.09-0.17s, after the foot strike. All but one case presented with a slightly inverted ankle joint at foot strike of 10-24 degrees, which should have incited the injury event. We recommend tennis players who perform repetitive sideward cutting motions to attempt 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 an ankle inversion sprain injury.

KEY WORDS: sports medicine, injury mechanism, injury biomechanics.

INTRODUCTION: Ankle ligamentous sprain is very common in sport, with the majority having an inversion or supination mechanism presented clinically and qualitatively (Fong, Hong, Chan, Yung & Chan, 2007). Understanding the injury mechanism, preferably with biomechanics quantities, is a key component for injury prevention (Bahr & Krosshaug, 2005). With the advance of sport biomechanics technique, numerous approaches have emerged for the quantitative understanding of injury mechanisms (Krosshaug & Bahr, 2005). 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 have occurred unexpectedly in a biomechanics laboratory with calibrated motion analysis settings. There were two recent such reports on ankle inversion sprain injury with reported kinematics data (Fong, Hong, Shima, Krosshaug, Yung & Chan, 2009; Kristianslund, Bahr & Krosshaug, 2011). In each study, the subject participated in a biomechanics test with a sideward cutting motion, and accidentally sustained an inversion ankle sprain injury.

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 (Zernicke, Garhammer & Jobe, 1977). 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 deal with this problem, Krosshaug and colleagues (Krosshaug, Andersen, Olsen, Myklebust & Bahr, 2005) 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 (Krosshaug, Nakamae, Boden, Engebretsen, Smith, Slauterbeck, Hewett & Bahr, 2007). The technique was recently further developed to investigate ankle joint motion (Mok, Fong, Krosshaug, Hung, Yung & Chan, 2011a), and was employed to investigate two cases during the 2008 Beijing Olympics (Mok, Fong, Krosshaug, Engebretsen, Hung, Yung & Chan 2011b). This study presents five cases in tennis and a comparison is provided with three previous studies for a better understanding of the mechanism of ankle ligamentous sprain injury.

METHODS: 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. Since there is no way to obtain the documented medical diagnosis of the athlete due to patient privacy, 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 paper (Table 1).

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

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

Details of the MBIM motion analysis were reported previously (Mok et al, 2011a, 2011b). 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 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 (Grood & Suntay, 1983). The ankle joint kinematics of each case was presented at every 0.02 second 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 (Wu, Siegler, Allard, Kirtley, Leardini, Rosenbaum, Whittle, D'Lima, Cristofolini, Witte, Schmid & Stokes, 2002), and were filtered and interpolated by Woltring's generalized cross-validation spline package with 15Hz cut-off frequency (Woltring 1986).

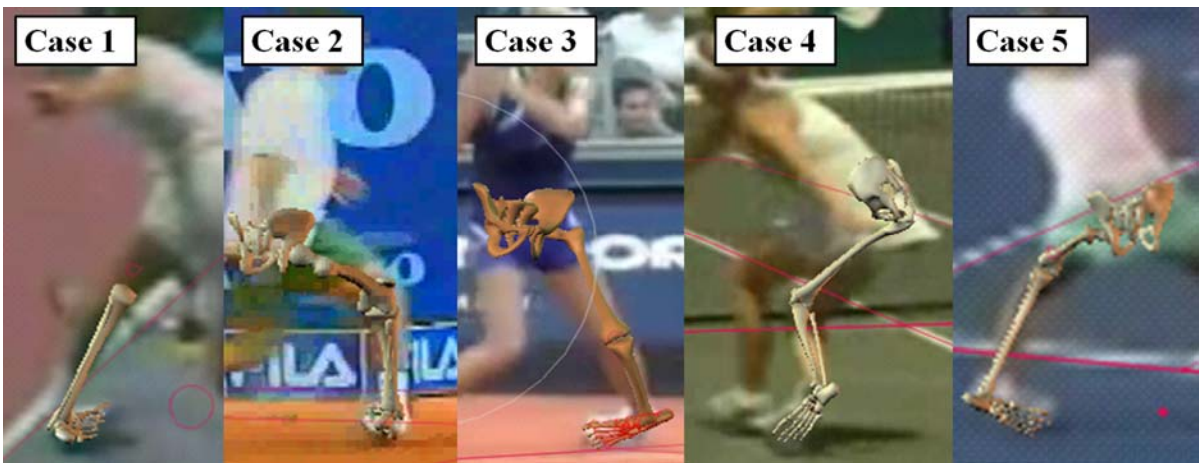

Figure 1: Screenshots from one view showing the moment with the greatest ankle inversion.

RESULTS: Figure 1 showed the moment with the greatest ankle inversion in each case from one view. Figure 2 showed the profile of ankle kinematics, while Table 2 showed the peak angle and velocity and the comparison with the cases reported in three previous studies.

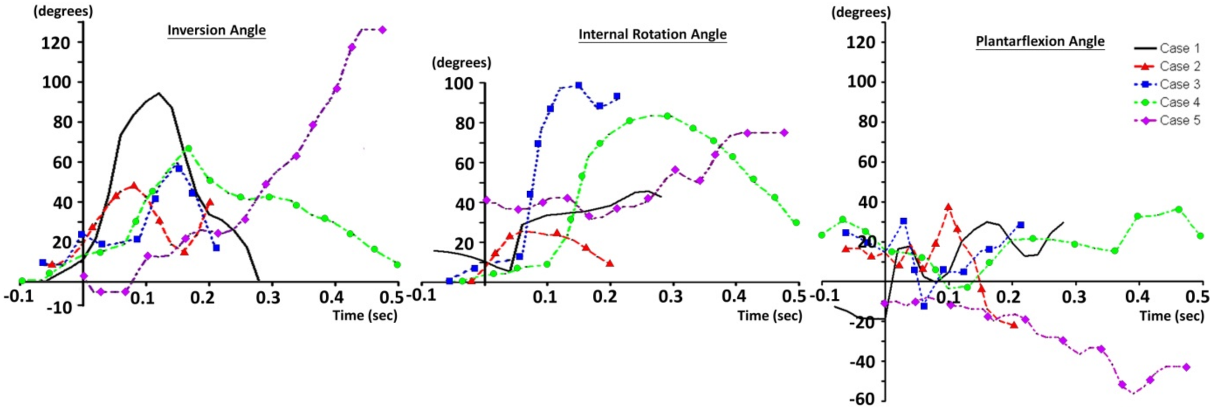

Figure 2: Profile of ankle inversion, internal rotation and plantarflexion in each injury incident.

DISCUSSION: Results showed great variations of the peak inversion and peak internal rotation in the 5 injury cases, which reached 48-126° and 26-99° 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 s after foot strike. This 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 (Fong et al, 2009; Mok et al, 2011; Kristianslund et al, 2011). Case 2 showed the same peak inversion but a smaller peak inversion velocity to the case presented by Fong and colleagues (2009), but a larger peak internal rotation and a larger internal rotation at the time of peak inversion, which were about 25-26° respectively. The case presented by Kristianslund et al (2011) also showed a small inversion of 23°, but a larger internal rotation of 55°. These findings suggested that the previously suggested clinical qualitative injury mechanism, which was supination, the combination of inversion and plantarflexion, may not be truly correct. 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.

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

	This study					Fong et al	Mok et al (2011)		Kristianslund
	Case 1	Case 2	Case 3	Case 4	Case 5	(2009)	Case 1	Case 2	et al (2011)
Peak inversion	94°	48°	59°	67°	126°	48°	142°	78°	23°
Peak inversion velocity	1488°/s	509°/s	837°/s	724°/s	941°/s	632°/s	1752°/s	1397°/s	559°/s
Peak internal rotation	46°	26°	99°	84°	75°	10°	~50°	~45°	~55°
Peak internal rotation velocity	1167°/s	412°/s	2124°/s	1312°/s	623°/s	271°/s	N/A	N/A	N/A
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

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 similarly 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 (Andersen, Floerenes, Arnason & Bahr, 2004). Another recent study (Morrison, Hudson, Davis, Richards, Royer, Dierks & Kaminski, 2010) also suggested that patients with chronic ankle instability developed after repeated ankle sprain injuries demonstrated a laterally shifted centre of pressure during running. 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 rather at neutral orientation at the foot strike, however, it ultimately increased gradually after 0.1s. 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 (2009). 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.

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. The quantified injury mechanism would help our further research to prevent the injury.

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