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Title	Kinematics analysis of ankle inversion ligamentous sprain injuries in sports - two cases during the 2008 Beijing Olympics		
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Keywords	video analysis, injury biomechanics, injury mechanism, ankle supination sprain		

1 **What is known about the subject**

2 Analyzing the injury video recordings provides valuable information such as joint

3 kinematics of specific sport injury. It contributes to the study of injury mechanism.

4 Previous study reported the kinematics of ankle sprain happened in laboratory.

5 However, difference exists between injury case in laboratory and injury case in real

6 game situation. Fong DTP, Hong Y, Yung PSH, Shima Y, Krosshaug T, Chan KM

7 (2009). Biomechanics of supination ankle sprain - a case report of an accidental injury
8 event in laboratory. American Journal of Sports Medicine, 37(4), 822-827.

9 **Adds to existing knowledge**

10 This paper reveals the kinematics of ankle inversion ligamentous sprain of the two
11 analyzed cases. The maximum joint angles and velocities are reported. It would be an
12 implication for further quantitative description of ankle inversion ligamentous sprain
13 injury mechanism.

14

15 **INTRODUCTION**

16 Ankle inversion ligamentous sprain is one of the most common injuries encountered
17 in sports (Fong et al., 2007; Fong et al., 2009a). A precise description of the injury
18 situation is a key component to understanding the aetiology and injury mechanism
19 (Bahr and Krosshaug, 2005). However, quantitative analyses on injury cases are
20 available only under rare circumstances due to coincidental calibrated video recording
21 (Zernicke et al., 1977). Previously, qualitative analysis of joint biomechanics was
22 reported on ankle injuries based on visual inspection (Andersen et al., 2004, Giza et
23 al., 2003). Fong and co-workers (2009b) reported the first ever kinematics analysis of
24 ankle inversion ligamentous sprain injury which accidentally happened in their
25 laboratory.

26 However, the occurrence of recording ankle inversion ligamentous sprain injury in the
27 laboratory is rare. Instead, injuries in sports are occasionally shown on TV with
28 multiple camera views, and those video recordings could be further analyzed to
29 explain the cause of injury. In order to develop a novel biomechanical analysis to
30 produce continuous measurement of joint kinematics from video recordings,
31 Krosshaug and Bahr (2005) introduced a Model-Based Image-Matching (MBIM)
32 motion analysis technique for investigating human motion from uncalibrated video
33 sequences, and employed the technique to determine the injury mechanism of anterior
34 cruciate ligament ruptures (Krosshaug et al., 2007).

35 In 2008, the International Olympic Committee (IOC) suggested an injury surveillance
36 system for multi-sports tournaments (Junge et al., 2008). The injury surveillance
37 system provides important epidemiological information. Junge et al. (2009) reported
38 the frequency, characteristics, and causes of injuries during the Beijing Olympics
39 Games in 2008. Based on the information from the injury surveillance system, the
40 injury incidents could be matched with the televised video recordings. Using the
41 MBIM motion analysis technique, the ankle joint kinematics of two ankle
42 ligamentous sprain injury cases could be reconstructed.

43 The purpose of this paper was to present the three-dimensional ankle joint kinematics
44 of two ankle sprain cases detected by the injury surveillance system in Beijing

45 Olympics Games 2008.

46

47 **METHOD**

48 Injury records from the Beijing games were published in 2009 by the IOC Medical
49 Commission (Junge et al 2009) In the IOC surveillance program, detailed information
50 of each injury included injury time, place, sports event and part of body injured. Video
51 recordings of some of the injury cases were obtained from the Olympic Broadcasting
52 System (OBS). The inclusion criteria selection of videos were that the athlete was
53 unable to continue the match or competition after the ankle inversion sprain motion,
54 and the injury motion was clearly shown by at least two camera views. Two ankle
55 inversion sprain cases were screened out for analysis. The first case was recorded
56 from high jump event; the athlete sprained her left ankle during the take-off. The
57 second case was captured in male field hockey match; the player sprained his left
58 ankle during running under an opponent's pressure.

59 **Model-Based Image-Matching motion analysis**

60 The video recordings were 1280x720 pixels in resolution, deinterlaced to 50Hz in
61 effective frame rate. The high jump case was captured by three video cameras, the
62 relative angle between cameras 1 and 2 was 31°, between 2 and 3 was 17°. The
63 relative surface area of the left below hip body part to the total video frame size was

64 2.1% (camera 1), 3.0% (camera 2) and 1.5% (camera 3). The field hockey case was
65 captured by two video cameras, the relative angle between cameras 1 and 2 was 43°.
66 The relative surface area of the left below hip body part to the total video frame size
67 was 1.1% (camera 1), 4.4% (camera 2). The video recordings were transformed from
68 their original format into uncompressed AVI image sequences using Adobe Premiere
69 Pro (version CS4, Adobe Systems Inc., San Jose, California, US). Then the sequences
70 were de-interlaced using Adobe Photoshop (version CS4, Adobe Systems Inc., San
71 Jose, California, US), and the image sequences were synchronized and rendered into 1
72 Hz video sequences by Adobe AfterEffects (version CS4, Adobe Systems Inc., San
73 Jose, California, US). The matchings were performed using 3D animation software
74 Poser® 4 and Poser® Pro Pack (Curious Labs Inc., Santa Cruz, California, US). The
75 surroundings were built in the virtual environment according to the real dimension of
76 the sport field. The models of surroundings were manually matched to the background
77 for the each frame in every camera view. The skeleton model from Zygote Media
78 Group Inc. (Prove, Utah, US) was used for the skeleton matching. No
79 anthropometrical measurements were available except subject's height. The segment
80 dimensions were therefore iteratively adjusted during matching process until finally, a
81 fixed set of scaling parameters was determined. The skeleton matching started with
82 the shank segment and then distally matched the foot, and toe segments frame by

83 frame. The joint angle time histories were read into Matlab (MathWorks, USA) with a
84 customized script for data processing. Joint kinematics was deduced by the Joint
85 Coordinate System (JCS) method (Grood and Suntay, 1983). The ankle joint
86 measurement standard was according to the recommendation of International Society
87 of Biomechanics (ISB) (Wu et al., 2002). The point of initial contact was defined as
88 the foot touchdown observed from multi-views synchronized video. The ankle joint
89 kinematics results from MBIM technique were filtered and interpolated by Woltring's
90 Generalized Cross Validation Spline package (Woltring, 1986) with 15Hz cut-off
91 frequency.

92

93 **RESULTS**

94 **High Jump Injury**

95 The injury occurred when the player performed the take-off stepping in the high jump
96 qualification. At the point of initial contact, the heel contacted the ground with the
97 ankle joint 30° inverted, 28° internally rotated and 5° plantarflexed, shown in Figure 1.
98 At that time, the athlete was twisting her torso for jumping over the bar. Her left ankle
99 was internally rotated because of the shank external rotation. At 0.08s after initial
100 contact, the inversion angle reached maximum, shown in Figure 2. At that time, the
101 ankle joint was 142° inverted, 37° internally rotated and 7° dorsiflexed. The

102 maximum inversion velocity was 1752°/s.

103 **Field Hockey Injury**

104 The injury occurred when the player was chasing the opponent with body contact. At
105 the point of initial contact, the ankle joint was 7° inverted, 4° internally rotated and
106 41° dorsiflexed, shown in Figure 1. After 0.02s, his forefoot slightly stepped on the
107 opponent's foot and the ankle inversion motion was triggered. At 0.08s after initial
108 contact, the inversion angle reached maximum, shown in Figure 4. At that time, the
109 ankle joint was 78° inverted, 27° internally rotated and 13° dorsiflexed. The
110 maximum inversion velocity was 1397°/s.

111

112 **DISCUSSION**

113 For the high jump case, the ankle joint was internally rotated by the twisting motion
114 of the torso at initial contact. This ankle joint orientation would favour the ankle joint
115 to perform a supination motion. In this case, the athlete failed to keep the ankle joint
116 under control. At 0.04s after the initial contact, the ankle joint changed from an
117 increase to a decrease in its plantarflexion angle. As shown in Figure 3, the ankle joint
118 was inverted until the lateral malleolus touched the ground. Plantarflexion could not
119 be performed in that joint orientation. Finally, the ankle joint sprain injury occurred at

120 0.08s after the initial contact. For the hockey injury, the ankle joint was in normal
121 orientation at initial contact. Immediately after the initial contact, the medial forefoot
122 contacted the opponent's foot and ankle joint inversion was triggered. The frame
123 sequence of the injury is shown in Figure 5. Similar to the high jump injury case, the
124 ankle joint was not plantarflexed at the point that maximum inversion angle was
125 obtained (0.08s after initial contact).

126 In summary, the kinematics of two injury cases and the injury mechanism were
127 different than those suggested by previous studies. Garrick et al. (1977) indicated that
128 the typical mechanism of ankle ligamentous sprain was a combination motion with
129 inversion, internal rotation and plantarflexion. Previous studies further suggested that
130 the injury motion was composed of inversion plus an internal twisting of the foot
131 (Safran et al., 1999), and plantarflexion with the subtalar joint adducting and inverting
132 (Vitale and Fallat, 1988). However, in the present two cases, plantarflexion was
133 found not to be involved in the ankle sprain injury motion. It implies that the subtalar
134 joint was less involved in the ankle inversion sprain injury. The maximum inversion
135 angle was reached at 0.08s after the initial contact. Konradsen et al. (1991) indicated
136 that the reaction time of the peroneal muscles in healthy male subjects with stable
137 ankles was 0.05 to 0.08s, and Fong et al. (2009b) suggested that inactive peroneus
138 tendons may be the reason the sprain occurred. Lastly, the maximum inversion

139 velocity of the two injury cases were 1752°/s for high jump injury and 1397°/s for
140 hockey injury, as shown in table 1. It is much larger than 632°/s which has been
141 reported by a previous study (Fong et al, 2009b). This suggests that the ankle joint
142 experienced an explosive inversion torque and subsequent abrupt kinematic changes.
143 In summary, the findings suggest that plantarflexion may not be as necessary a
144 component of ankle supination sprain motion as previously believed. Instead,
145 inversion and internal rotation should be considered when designing preventive
146 measures. Furthermore, short injury duration and high inversion velocity implies that
147 preventive measures should be able to resist a large ankle torque in a very short period
148 of time. From the aspect of computer modelling, the kinematics can be further
149 analyzed by to calculate the internal stress and liagmentous tension (Chao et al.,
150 2007).

151 This study is limited to two cases screened out for MBIM motion analysis. Before
152 generalizing the results to the injury mechanism of ankle inversion sprain, more injury
153 cases are needed to be analyzed and reported. At this point, the results of this study
154 can merely point out the research gap and spark further discussion on the injury
155 mechanism. The IOC Medical Commission is working on an improvement allowing
156 better connection between the injury surveillance system and videos. In addition,
157 information on subject anthropometric data would increase the accuracy of the

158 analysis (Krosshaug et al., 2007). In the present study, the subject anthropometric data
159 other than height were not available because those measurements were not included in
160 the injury surveillance system.

161

162 **CONCLUSION**

163 This study reported the ankle joint kinematics of ankle inversion ligamentous sprain.
164 The ankle ligamentous injury resulted from a motion combining internal rotation and
165 inversion on the ankle joint, instead of plantarflexion and inversion which was
166 traditionally regarded as the typical injury mechanism. Furthermore, the maximum
167 inversion angle occurred at 0.08s after initial contact. The inversion velocities
168 measured were 1752°/s for high jump injury and 1397°/s for hockey injury. The
169 results from the MBIM technique could contribute to the understanding of the injury
170 mechanism of ankle supination sprain injury.

171

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182

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238

239 **FIGURES LEGEND**

240 Figure 1. Ankle joint kinematics of the player during the ankle supination sprain
 241 injury. Time zero represented the point of initial contact

242 Figure 2. Captures at the point of maximum inversion angle for high-jump injury

243 Figure 3. Frame sequence of high-jump injury. Time zero represented the point of
 244 initial contact

245 Figure 4. Captures at the point of maximum inversion angle for field hockey injury

246 Figure 5. Frame sequence of field hockey injury. Time zero represented the point of

247 initial contact

248

249

250

251 **TABLE**

252 Table 1. The descriptive data of ankle joint kinematics of the injury cases

	High Jump Case	Field Hockey Case	Fong et al. (2009)
Max. Inversion angle	142°	78°	48°
Max. Inversion velocity	1752°/s	1397°/s	632°/s

253