Portuguese Journal of Sport Sciences
11 (Suppl. 2), 2011

COMPUTATION OF ANKLE TORQUE IN DIFFERENT STRATEGIES OF LANDING BY DYNAMIC MODELING

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Ankle joint injury often occurs in sports. The purpose of this study was to compute ankle torque under different strategies of landing using human body movement simulation during landing for males and females. Kinematic and kinetic data were given to model and ankle torque under three strategies of landing was computed. Results showed that in first strategy there was a minimum value of peak ankle torque for both males and females. In second and third strategies by increasing plantar flexion of ankle, peak ankle torque was increased for both males and females. Results were in agreement with previous experimental investigations.

KEY WORDS: ankle injuries, inverse dynamic, biomechanical modeling.

INTRODUCTION: In many sports, ankle is the most vulnerable joint of the body and the majority of the injuries was ligamentous sprain, so that 80% of all injuries included by sprains (Fong et al., 2009). Ankle sprain causes instability in ankle joint (Kannus & Renstro¨m, 1991), and it has been found that 47% of ankle sprains occurs in ankles that had been previously sprained (Ekstrand & Gillquist, 1983). Lateral sprain injuries, particularly anterior talo-fibular ligament sprain is common in sport injuries (Brostom, 1964; Staples, 1975). A typical mechanism that contributes to increase ankle sprain, is excessive plantar flexion at touch-down (Fuller, 1999; Wright et al., 2000). This inappropriate foot positioning prior to touch-down is a potential cause of the increased sprain. Other risk factors are supination (Fuller, 1999) and ankle inversion when the foot is plantar flexed (Colville, 1994). The more plantar flexion of ankle at touchdown, the higher incidence of excessive supination (Wright et al., 2000). As the plantar flexion angle of ankle at touchdown increased, then the moment arm of ground reaction force about the subtalar joint axis also increased (Shapiro et al., 1994; Barrett & Bilisko, 1995). Ankle sprain occurs more frequently in landing, when athlete's foot touches the ground (Wright et al., 2000) and it has been shown that landing maneuvers are integral tasks among many intensive high-risk sports (Dufek & Bates, 1991; Hrysomallis, 2007). Johnson and Markolf (1983) found the anterior talo-fibular ligament to be the primary restraint to inversion at all flexion angles of ankle. In plantar flexion anterior talo-fibular ligament is parallel to the long axis of the foot and assumes a more parallel alignment with the long axis of the fibula, thus making it more susceptible to injury in this position (Marder, 1994; Bahr et al., 1997; Nigg et al., 1990). It has been shown that strain in this ligament increases as the ankle is moved progressively through plantar flexion (Colville et al., 1990; Renstrom et al., 1988).
Using inverse dynamic method, Decker et al., (2003) estimated lower extremity joint kinematics, kinetics and energy profiles for males and females during 60 cm drop landing. They analyzed the human motion by considering the whole body as four segments, with three joints as ankle, knee and hip. They showed that ankle peak torque was higher in males than in females, although not significant. Also negative power and ankle energy absorption in ankle was higher in females than in males. The aim of this study was to determine the ankle torque under different strategies of landing.

METHODS: Using anthropometric data, 5-link biomechanical models were built to analyze the ankle torque for male and female. The proposed models consist of five rigid links as toe, hindfoot, shank, thigh and head-arms-trunk (HAT) and four revolute joints in the sagittal plane which were prepared using SimMechanics software (MATLAB®, R2010, The

MathWorks). Anthropometric data consisting of length, weight, centre of gravity and inertial properties of each link, were obtained from Winter (2005). Input data consisted on motion kinematics during drop landing from 60 cm height and the vertical ground reaction force. First strategy was defined as landing on plantar surface of foot, while initial ankle position at contact was changed. Second strategy was defined as toe-landing in which the initial position of ankle was supposed to be unchanged, while the angle between hindfoot and ground was changed. Third strategy was defined as toe-landing in which the initial position of hindfoot was supposed to be unchanged, while the angle of ankle with ground was changed. Here we supposed the angle of hindfoot and ground 30º for females and males. Using inverse dynamic approach, ankle torque was obtained in all mentioned strategies. Ankle torques and vertical ground reaction force was normalized to reduce anthropometric differences (Pierrynowsky & Galea, 2001).

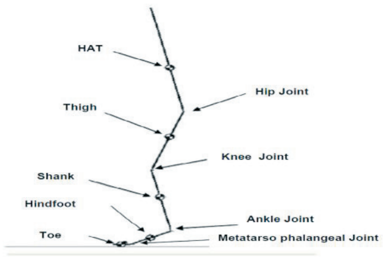

Figure 1: The model we have proposed for simulation of different landing strategies.

RESULTS: Results showed that in first strategy there was a minimum value for peak ankle torque and this minimum value for females was 65% higher than males. In second strategy, increasing initial plantar flexion, caused an increase in peak ankle torque for both females and males. By changing the angles of hindfoot with ground that ranged from 20 to 50 degree, peak ankle torques for females were 10% to 25% lower than males; and by changing the angles of hindfoot with ground that ranged from 10 to 20 degree, peak ankle torques for female were 14% to 63% higher than males. In third strategy by increasing initial plantar flexion of ankle, peak ankle torque increased in both females and males; and peak ankle torques for females were 23% to 49% lower than males. Also it has been shown in a particular condition, in which position of hindfoot with ground was 30º for females and 25º for males, and ankle angle at touch-down was 21.3º for females and 11.3º for males, that peak ankle torque for female was 4% lower than male; and female demonstrated 34% higher energy absorption from ankle compared to male.

Table 1
Summary of results obtained by dynamic modeling.

Strategy	Variable	Range of Variable (deg)	Minimum Peak Torque in Males and Females (Nm/(%BW*ht))		Angle of variable in Minimum Peak Torque in Males and Females (deg)	
First Strategy	Position of Ankle with Ground	38.7-108.7	Females 12.81	Males 7.72	Females 68.7	Males 88.7
Second Strategy	Position of Hindfoot with Ground	10-50	Females 6.02	Males 5.24	Females 20	Males 10
Third Strategy	Position of Ankle with Ground	70-130	Females 5.90	Males 11.61	Females 130	Males 130

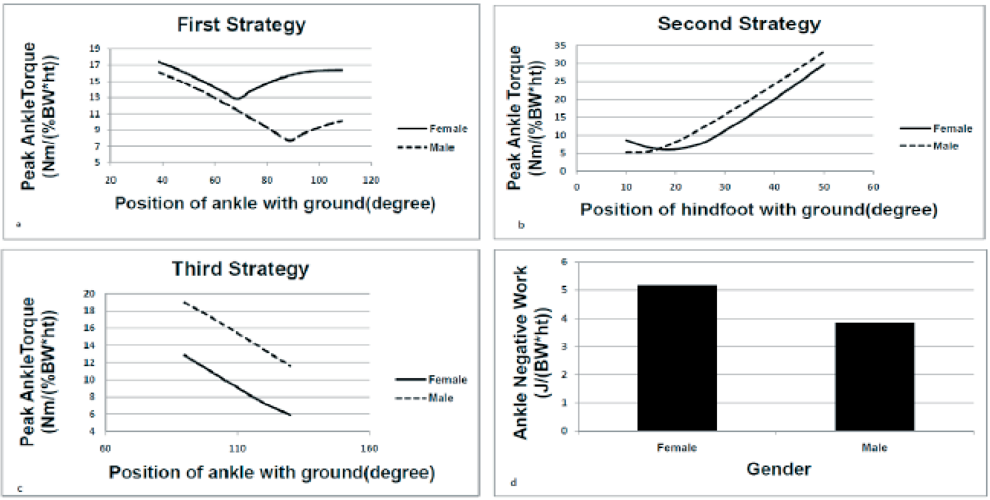

Figure 2: (a) Peak ankle torque in first strategy for males and females, (b) Peak ankle torque in second strategy for males and females, (c) Peak ankle torque in third strategy for males and females, (d) Diagram of ankle negative work for males and females.

DISCUSSION: In first strategy, minimum value of peak ankle torque occurs in females when they touch the ground with more plantar flexed ankles than in males. In second and third strategies, when ankle was positioned in more plantar flexed position, ankle torque became higher. This result was in agreement with previous experimental studies (Fuller, 1999; Wright et al., 2000). Other studies showed that inversion sprains often occur when the foot was plantarflexed (Renstrom & Konradsen, 1997; Fuller, 1999) and the anterior talo-fibular ligament, which is loaded when the foot is plantarflexed and supinated, was the most frequently sprained ligament of the ankle (Saunders, 1980). Therefore, our model confirmed that susceptibility to sprains is increased by initial plantar flexion.
Results were further supported by the findings presented in the literature (Decker et al., 2003). We simulated a particular condition, in which the average kinematic and kinetic data of females and males in 60 cm drop landing were imported to the model (Decker et al., 2003). The results of this condition for ankle torques, were similar with the results of experimental study by Decker et al., (2003), however he did not mention the position of hindfoot at initial contact with ground. Decker et al., (2003) showed that peak ankle torque in females was 5% lower than in males. Our results also showed that in a particular condition, which was previous described, peak ankle torque in females was 4% lower than in males. Decker et al., (2003) also showed that ankle energy absorption in females was 52% higher than in males and our results showed that this value was 34% higher than in males. Schmitz et al. (2007) reported that in single leg landing, females demonstrated 11% higher ankle energy absorption than males. These results are in agreement with previous experimental studies mentioning that men are 80.4% more susceptible for ankle injuries than women (Fong et al., 2008). These differences of ankle torque and ankle negative work between genders may because of anthropometric differences that exist between two genders. Also different strategies of landing affect ankle torque.

CONCLUSION: By comparison of this model and previous investigations, it has been shown that this method is a useful tool to simulate any condition for each person and to identify whether those conditions probably lead to injuries or not. By movement simulation, we can be able to predict joint kinetics in those conditions which may be difficult to obtain by experiment.

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