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The shifting of the torsion axis of the foot during the stance phase of lateral cutting movements

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ABSTRACT

Previously, foot torsion has been studied with respect to peak angles during athletic movements. Athletic footwear often contains a torsion element that dictates a torsion axis of the shoe. The location of the axis of rotation of the foot is, however, unknown. Therefore, the purpose of this study was to describe the torsion axis location during the stance phase of lateral cutting movements. Thirty-nine subjects performed a barefoot lateral jab and 19 subjects performed a barefoot shuffle cut. Markers were placed on the fore- and rearfoot and their movement was quantified using a 3-D video system. The torsion axis location was determined using a modified finite helical axis approach during the stance phase while the torsion angle was calculated as the amount of rotation around the torsion axis. At the beginning of the stance phase, the axis was located on the medial aspect of the foot. During the stance phase, the axis shifted towards the lateral side of the foot before the axis moved back to the medial aspect of the foot at the end of stance. For both movements significant correlations between the axis location in the vertical and medio-lateral directions and the torsion angle were found. With larger torsion (forefoot inversion) angles the axis was in a more lateral and plantar location within the foot. With this knowledge, a shoe torsion system where the shoe torsion axis location is in agreement with the foot axis location could be developed.

1. Introduction

Torsion of the foot, which has been defined as the relative rotation between the forefoot and the rearfoot in the frontal plane, has been studied for athletic movements such as lateral cutting (Segesser et al., 1989; Stacoff et al., 1993). During lateral cutting movements, the foot typically touches the ground first with the forefoot, while the shank is at an angle of up to 33° to the vertical (Luethi et al., 1986). In order to keep the ankle joint stable, the rearfoot needs to stay aligned with the shank. This leads to torsion angles of up to 20° during lateral cuts (Davis et al., 2009). In an athletic setting, cutting movements are mainly performed wearing shoes. Therefore, the influence of footwear on foot torsion became of general scientific interest. It was found that torsional stiff shoes reduced the peak torsion angles, which may put the ankle at a higher risk of injury. Consequently, torsion shoes were introduced which contain a torsion bar in the outsole that reduces torsional stiffness while maintaining the midfoot bending stiffness (Segesser et al., 1989). The location of the torsion bar within the shoe was chosen according to estimates based on foot anatomy; the location of the foot torsion axis, however, is unknown.

The movement of a body segment relative to another body segment can be described with an axis that the body rotates around and translates along (Kinzel et al., 1972; Spoor and Veldpaus, 1980). This axis is referred to as the finite helical axis (FHA) because the movement of the body follows a helical motion. When there is no translation between the segments, which is a reasonable assumption for most human joints, the FHA approach determines the rotation axis. Calculating the actual rotation axis is an advantage over other methods that describe three-dimensional kinematics, e.g. Euler angles or angles calculated with a joint coordinate system, where the rotation is expressed about predefined axes (Zatsiorsky, 1998). However, the FHA is prone to error caused by noise or violations of the rigid body assumption especially when rotations are small (de Lange et al., 1990; Woltring et al., 1985).

The finite helical axis has been used to describe the motion of various joints. Tuijthof et al. (2009) were able to determine differences in the helical parameters of the ankle joint between a healthy population and a patient with chronic ankle instability. A study by Arndt et al. (2004) found great differences between subjects in the helical axis orientation of the ankle joint during walking. The finite helical axis method was used to study the knee joint in order to further the understanding of knee kinematics

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(Sheehan, 2010; van den Bogert et al., 2008). van den Bogert et al. (2008) found that the shift of the helical axis, which resulted from a gliding movement between femur and tibia, was not dependent only on the amount of knee flexion. The helical axis was calculated for the two intervals before and after the transition from flexion to extension during running. The amount of knee flexion at the beginning of the first interval was equal to the amount of knee flexion at the end of the second interval. However, the axis during the flexion interval was located about 10 mm more anterior compared to the axis during the extension interval.

A method to calculate the foot torsion axis based on the FHA method has previously been described (Graf et al., 2012). According to previous work describing the FHA for joints other than the midfoot (van den Bogert et al., 2008), it can be hypothesized that the torsion axis location moves during stance. Therefore, the purpose of this study was to describe the FHA location and orientation during the stance phase of a lateral jab and a shuffle cut. It was hypothesized that the axis location is dependent on the magnitude of the torsion angle.

2. Methods

Nineteen subjects (mean ± std: 24.2 ± 4.8 years; 186.1 ± 6.6 cm; 83.3 ± 9.1 cm) were recruited for this study and gave informed written consent. They were all free from lower extremity injuries for 6 months prior to data collection. The study protocol was approved by the institutional research ethics board. Each subject performed seven repetitions of a shuffle cut with bare feet at maximal effort. During the shuffle cut, the subjects performed a shuffle movement with a 180° cut on the force plate (Fig. 1). The second movement was a lateral jab which consisted of a spring, a lateral side step with the right leg onto the force plate followed by a 45° cut towards the left side. The lateral jab movement was performed by an additional 20 subjects leading to a total of 39 subjects for this movement (mean ± std: 24.7 ± 4.6 years; 180.2 ± 9.5 cm; 76.4 ± 10.8 kg). The additional 20 subjects were part of another study, which did not include the shuffle cut movement. Three retro-reflective markers were placed each on the forefoot and rearfoot: dorsal aspect of the first, second, and fifth proximal phalange, and medial, posterior, and lateral aspect of the calcaneus. Two additional markers were attached to the head of the first metatarsal and the head of the fifth metatarsal to approximate the metatarsophalangeal joint axis during a standing neutral trial. The marker trajectories were collected using a Motion Analysis system with eight high-speed digital cameras (Motion Analysis Corporation, Santa Rosa, CA, USA) with a sampling rate of 240 Hz. In order to define the stance phase, ground reaction forces were recorded using a Kistler force plate operating at 2400 Hz (Kistler AG, Winterthur, Switzerland). Before the analysis, the kinematic and kinetic data were filtered using a low-pass Butterworth filter (4th-order) with a cut-off frequency of 12 Hz and 50 Hz, respectively.

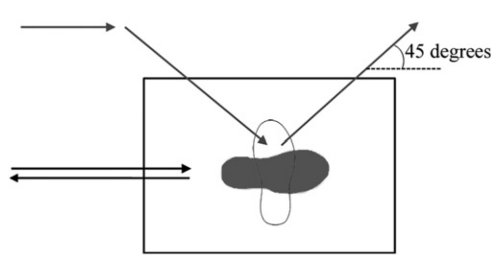

Fig. 1. Schematic display of the performed movements; lateral jab: grey; shuffle cut: black.

The midfoot rotation axis location and orientation, which expressed the movement in the midfoot in all planes, were calculated using a modified finite helical axis approach at each percentile of the stance phase using Matlab software (Version 7.5, The MathWorks Inc., Natick, MA, USA) (Graf et al., 2012). The midfoot rotation axis location was approximated as the torsion axis location based on the assumption that rotations other than torsion in the midfoot are small. The axis location was expressed relative to the origin of the rearfoot coordinate system, which was at the marker placed on the posterior part of the heel. The orientation of the midfoot rotation axis was expressed through two angles, alpha 1 and alpha 2. Alpha 1 represented the inclination of the axis in the sagittal plane while alpha 2 was the angle of the axis from the sagittal plane towards the lateral side. The orientation of the torsion axis was predefined as perpendicular to the frontal plane of the rearfoot coordinate system. The torsion angle was determined as the rotation about the torsion axis.

Pearson's correlation coefficients and the significance of the correlations between the axis locations and the magnitude of the torsion angle were calculated with Matlab software (Version 7.5, The MathWorks Inc., Natick, MA, USA).

3. Results

For both the lateral jab and the shuffle cut the axis was medial to and slightly above the rearfoot reference point at the beginning of the stance phase. It then moved to the lateral side and reached a peak lateral location of approximately 35 mm from the reference point during mid-stance. At the same time the axis moved to a lower location and reached a peak at around 10 mm below the reference point. Towards the end of stance, the axis moved back to the medial side of the foot (Figs. 2 and 3A). The axis trajectory for each subject was analysed and a similar shifting pattern was found for the majority of the subjects. The data of all subjects were normally distributed. Therefore, the shifting of the average axis over all subjects was analysed. The average axis of all subjects showed similar movement during the stance phase between the lateral jab and the side-shuffle cut (Figs. 2 and 3A). For the shuffle cut the peak lateral location reached earlier instance than for the lateral jab.

During the lateral jab, at the beginning and end of the stance phase alpha 1 (the inclination of the axis in the sagittal plane) was larger than 5°, but, between 29% and 61% of the stance time this angle was smaller than 5° indicating only very small amounts of

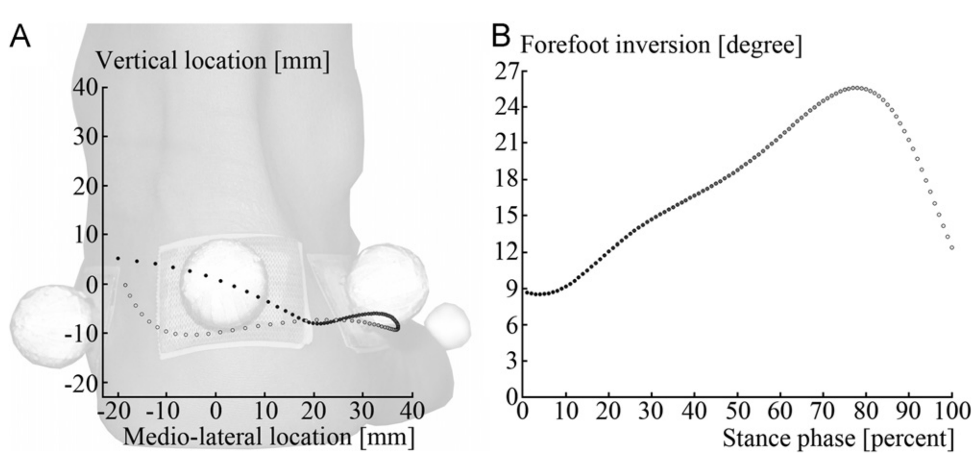

Fig. 2. Average torsion axis location (A) and average torsion angle (B) during the stance phase of a lateral jab ($n=39$).