Stiffness of the First MTP Joint in Athletic Activities

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I. INTRODUCTION

Hyperextension of the first metatarsal phalangeal (1MTP) joint is a common injury in field sports, notably American Football (football) [1]. Cadaveric data indicate that hallux dorsiflexion to 78° results in a 50% risk of hyperextension injury [2]. A 1MTP joint dorsiflexion angle of 78° is near the range of motion limit for young men [3] and lies at about the 95th percentile in the distribution of 1MTP angles observed in performance activities [4-5]. Thus, it is not at all surprising that 1MTP hyperextension injuries are quite common. Footwear designed to preclude hyperextension injuries must be sufficiently stiff at the extreme to limit hallux extension to less than the injury threshold, but not so stiff at lesser angles as to impede performance. Very little data characterizing 1MTP joint functional stiffness are available. Herein, hallux extension angles are measured and 1MTP joint moments are estimated under a set of assumptions that allow 1MTP joint functional stiffness to be determined within a reasonably well defined range of uncertainty.

II. METHODS

The kinematics and kinetics of nine professional athletes performing tasks routinely used to assess player athleticism were recorded in a motion laboratory [5]. The athletes performed barefoot. The 3D motion of reflective markers was tracked using a seven-camera motion capture system operating at 240fps (Vicon, Los Angeles, CA, USA). Synchronously, ground reaction forces (GRF) were measured using force plates sampled at 1200hz (AMTI, Watertown, MA, USA). The kinematics and kinetics of running were captured during a drill referred to as the shuttle run, wherein the athlete dashes approximately 8.5 meters from one point to another, preceded and followed by lateral motion. Foot models were scaled to the anthropometry of each athlete. On each lower limb, six markers were used to define foot motion, first metatarsal plantar flexion angle and 1MTP joint angle [4]. Inverse kinematic and inverse dynamic analyses were performed using OpenSim [6]. 1MTP joint moments were calculated using two different assumptions. The first and more conventional assumption was that once the center of pressure (CoP) was distal to the first metatarsal head, the GRF acted on the hallux and generated a moment about the 1MTP joint. The second assumption was that once the CoP was distal to the first metatarsal head, the GRF acted at two points, the first metatarsal head and the distal hallux, distributed in proportion to the ratio of distances from the CoP to the two locations (Figure 1). Only the force acting on the distal hallux contributed to the 1MTP joint moment. The measures of 1MTP joint angle and estimates of 1MTP joint moment were combined to determine 1MTP joint stiffness in walking, running, motion initiation and

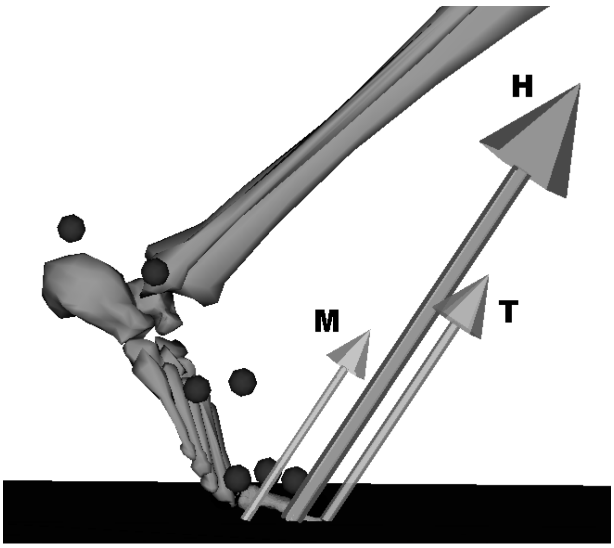

Figure 1. GRF acting on Hallux. H—total GRF acting on the Hallux at the CoP. M—GRF component acting on foot at the MET1 distal head and not contributing to 1MTP joint moment, T—GRF component acting on the distal Hallux and contributing to 1MTP joint moment.

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vertical jumping. Because footwear and protective measures differ among player positions, the nine athletes were subdivided into three groups of three subjects: speed players (receivers and running backs, 89.5±6.1kg), power players (linemen, 135.9±14.9kg) and hybrid players (defensive backs and tight ends, 109.5±2.6kg).

III. INITIAL FINDINGS

While power players, e.g. linemen, had the greatest mass, hybrid players produced equivalent peak moments in running. Assumption one derived moments were greater than moments calculated under assumption two. However, overall the moments were similar, indicating a reasonably small range of uncertainty for the moment estimates. The average peak 1MTP joint moment for running ranged from 23Nm for speed players, 38Nm for hybrid players and 40Nm for power players. The 1MTP joint stiffness before the peak moment (Figure 2, A to B) was approximately 3Nm/degree for speed players, 4Nm/degree for hybrid players and 6Nm/degree for power players. In comparison, the average peak ankle moments were in the range of 250 to 350Nm and the ankle stiffness was ~10Nm/degree.

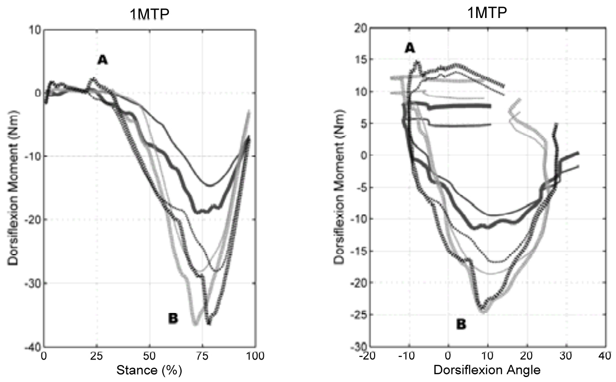

Figure 2 1MTP moment vs stance time and moment vs angle curves for running. Wide Lines—Assumption 1; thin lines—Assumption 2. Solid Black—speed players; light dashed—hybrid players; dark dashed—power players. For each moment vs angle curve, the mean moment and mean angle have been subtracted.

IV. DISCUSSION

Stefanyshyn found that 1MTP joint moments estimated from forces allocated according to the measured plantar pressure distribution were 3 to 7% less than assumption one moments [7]. Thus, the actual moments very probably lie between the assumption one and two values as desired. Stefanyshyn also found, as we did, that the distributed force peak moment occurred slightly later than the assumption one peak. The average peak assumption one moment for five runners studied by Stefanyshyn was approximately 60Nm, somewhat higher than we are reporting. However, these college level competitive runners were shod and running on a straight track, not dashing between obstacles as were our athletes. The shuttle run is representative of the performance of athletes in football, but the dash distance in the motion laboratory was approximately 50% of the typical field drill distance. Stefanyshyn did not estimate 1MTP joint stiffness, but reported significant energy dissipation at the MTP joint, consistent with the hysteresis seen in our moment-angle curves. Reducing energy dissipation at the MTP joint by increasing mid-sole stiffness has been found to reduce the metabolic cost of running in athletes, particularly heavy athletes [8], indicating that an appropriate increase in shoe stiffness may not only reduce injury risk but also improve athletic performance. The data presented herein are unique in that they were derived from professional athletes performing a football specific task and characterize 1MTP joint functional stiffness. Our results will inform the design of protective footwear and contribute to the overall understanding of athletic performance and injury mechanisms.

V. ACKNOWLEDGEMENTS

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