A Comparison of Barefoot versus Shod Running Using 3D Gait Analysis

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Introduction
The impact forces incurred by a runner can be up to several times their body weight (1). Although running shoe design has focused on increased cushioning to lessen this impact, it has been suggested that barefoot adaptations made when barefoot running result in injury prevention (2). It is not known what biomechanical changes occur in the lower extremities when running barefoot versus shod. It is the purpose of this study to evaluate the kinematics and kinetics of the lower extremities during barefoot and shod running.

Statement of Clinical Significance
A better understanding of the modifications in biomechanics of the lower extremities during both barefoot and shod running conditions may lead to a better understanding of some injury mechanisms as well as possible solutions through adaptations in running technique.

Methodology
Twenty subjects (13 females and 7 males) who were regular recreational runners were included in this study. Average age was 38±10 years. None had any current running injuries or previous surgery on the lower extremities. All underwent a clinical examination including assessment of bony torsions. All runners trained exclusively in shoes and were not informed of the purpose of the study. During data collection each subject wore his or her regular shoes. Shoe thickness was measured at the heel and toe to allow for calculation of ankle angle in the shod condition. Each subject was tested using three-dimensional motion analysis techniques first in the shod (running) and then barefoot (walking and running) conditions. The exact methods have been previously described (3). During data collection, all subjects were asked to run at a comfortable training pace with no suggestion about technique. A minimum of three trials for each side for each condition were collected and a representative trial was selected for analysis. Differences between barefoot and shod conditions were assessed using a paired two-tailed Student's T-test ($p<0.05$). The terminology of absorption and generation phases for the first half and latter half of stance, respectively will be adopted for discussion of the results (4).

Results
Temporal data collected revealed a significant reduction ($p<0.04$) in running velocity from 180±35 when shod to 170±22 cm/s when barefoot. This was consistent with the significant ($p<0.002$) reduction in stride length from 120±16 when shod to 116±10 cm when barefoot with a similar cadence. There were no significant changes in trunk, pelvic and hip kinematics and hip kinetics between the two conditions. Significant changes were noted in the loading and propulsion phases at the knee and ankle kinematics and kinetics (Tables 1 and 2). Extensor moments and power generation and absorption were reduced at the knee when barefoot.

Table 1: A comparison of sagittal plane knee joint kinematics and kinetics during barefoot and shod running.

	Angle at Initial Contact (deg)	Peak Flexion Absorption Phase (deg)	Peak Extensor Moment Stance (N.m/kg)	Peak Power Absorption Absorption Phase (W/kg)	Peak Power Generation Propulsion phase (W/kg)	Peak Flexion Swing (deg)
Shod	15±4	33±5	0.91±0.37	-2.41±1.11	1.66±0.80	81±13
Barefoot	15±4	30±5	0.76±0.39	-1.75±1.12	1.21±0.82	79±13
P <0.05		*	*	*	*	*

Table 2: A comparison of sagittal plane ankle joint kinematics and kinetics during barefoot and shod running.

	Angle at Initial Contact (deg)	Peak Dorsi-flexion Stance (deg)	Peak Plantar Flexion Gait Cycle (deg)	Sagittal Plane Range of Motion (deg)	Peak Plantar Flexor Moment Propulsion Phase (N.m/kg)	Peak Dorsi-flexor Moment Absorption Phase (N.m/kg)	Peak Power Absorption Absorption Phase (W/kg)	Peak Power Generation Generation Phase (W/kg)
Shod	3±6	12±5	-29±5	41±6	1.69±0.63	-0.13±0.10	-1.44±0.94	5.33±1.75
Barefoot	1±9	19±3	-24±6	42±6	1.80±0.64	-0.09±0.11	-2.60±1.56	6.94±2.63
$P<0.05$		*	*		*	*	*	*

Also when barefoot the plantar flexor moments and power absorption and generation were increased at the ankle. There was a greater incidence of a heel initial contact gait (dorsiflexor moment in absorption phase) during shod running (32/40) in comparison to barefoot running (20/40). There was a significant increase in the work done on the ankle barefoot (-0.15±0.11 Joules) in comparison to shod (-0.07±0.06 Joules). Similarly, there was a significant increase in the work done by the ankle barefoot (-0.52±0.20 Joules) in comparison to shod (-0.43±0.14 Joules).

Discussion

The data suggest that runners automatically change their running biomechanics when asked to run barefoot. In general, to compensate for reduced cushioning under the foot when running barefoot the majority of runners in this study either adopted a foot flat or toe initial contact pattern, or reduced the peak ankle dorsiflexor moment during the absorption phase. The slight increase in plantar flexion in combination with the removal of the shoe (mean heel height of 2.8 cm, which was 1.2 cm greater than forefoot thickness) may have resulted in the decreased incidence of heel contact when barefoot. There were no differences in knee angle at initial contact to explain the change in foot contact pattern. The lack of protective cushioning when barefoot also resulted in changes at both the ankle and knee kinematic and kinetics in stance. The data suggest that the impact absorption was completed more at the ankle and less at the knee when barefoot in comparison to shod. The runners in this study reduced the demand on the knee by reducing the peak knee flexion, extensor moment and power absorption (and associated eccentric contraction of the quadriceps) during the absorption phase during barefoot versus shod running. These findings may have clinical implications with respect to anterior knee pain, which accounts for up to 30% of all running injuries (5). That is, adopting a foot flat or toe initial contact pattern may reduce the knee loads during stance and thus anterior knee pain.

The runners in this study increased the demand on the ankle by increasing the peak ankle dorsiflexion, ankle dorsiflexion velocity and power absorption during the absorption phase in barefoot running versus shod running. The injury implications of this increased power absorption and associated eccentric contraction of the plantar flexors on the tendo-Achilles, are unclear. It is possible that through appropriate training, adoption of a foot flat or toe initial contact running technique would decrease the anterior knee pain without introducing Achilles tendon injuries or excessive plantar flexor fatigue. It is our goal to examine these ideas with subsequent studies of a group of runners with chronic knee pain.

References

1. Bergmann et al. Journal of Biomechanics, 28:817-827, 1995.
2. Robbins et al. Medicine Science in Sports and Exercise, 19:371-375, 1998.
3. Davis et al. Human Motion Analysis: Current Directions and Future Applications, 17-42, 1996.
4. Ounpuu S. Clinics in Sports Medicine, 13:843-863, 1994.
5. James et al. Biomechanics of Distance Running, 249-269, 1990.