INTRODUCTION

Little research has quantified medial longitudinal arch (MLA) stiffness during dynamic activity, such as walking and running. While it is commonly believed that pes cavus feet are more rigid and pes planus feet are more mobile, this has not been well supported with research. It has been noted that only 9% of the variance in arch stiffness from sit-to-stand was accounted for by static arch height index, with a higher arch being slightly more rigid [3]. During running the MLA collapses during the initial stages of the stance phase and then reforms during the latter stage. It has been hypothesized that during arch collapse the foot acts as a “mobile adapter” to help absorb some of the energy of the impact. During the propulsive phase the foot acts as a “rigid lever” to efficiently transfer energy generated by the muscles to the ground. If the structures of the arch play a role in this transformation from mobile adapter to rigid lever it would be reasonable to expect a change in the arch stiffness between the collapse and the reformation of the arch. Thus, the purpose of this study was to examine MLA stiffness during these two stages and to note how they change after a prolonged run.

METHODS

Eleven healthy participants (8 males, 3 females; age: 19.8±1.3 yrs; height: 1.73±0.06 m; mass: 69.4±10.0 kg; weekly mileage: 16.9-80.5 km) ran at a comfortable speed (3.28±0.35 m/s) barefoot across a force platform before and after a shod treadmill run (35-45 minutes) at the same speed. All but one subject used a heel-strike pattern. Reflective markers were placed on the right first metatarsal head (2 cm from ground), navicular tuberosity, and medial calcaneus (3 cm (female) or 4 cm (male) from the posterior aspect of foot, 2 cm from ground). An 8 camera motion capture system (200 Hz) and AMTI force platform (1000 Hz) collected marker position and ground reaction forces (GRF). Arch length was defined as the 3-D distance from the medial calcaneus to the first metatarsal head. Navicular height was defined as the 3-D perpendicular distance from that arch length line to the navicular. Changes in arch length and navicular height (displacement) were expressed in relation to a seated trial. Arch stiffness was calculated as the slope of a least-squares regression line fit through the resultant GRF and navicular displacement. Two arch stiffness values were calculated: 1) arch stiffness for the first part of stance (AS1) and 2) arch stiffness for the second part of stance (AS2). AS1 was calculated from 15% of stance to maximum navicular displacement (~55% stance). AS2 was calculated from maximum navicular displacement to 85% of stance. Mean r² values were calculated to determine the linear fit of the regression line for arch stiffness.

RESULTS AND DISCUSSION

A typical deformation by force curve is presented in Figure 1 with the first and last 15% of the stance phase removed. Prior to the run the mean AS1 arch stiffness was 153.7±56.5 N/mm (r²=0.79) while the mean AS2 arch stiffness was 241.0±90.5 N/mm (r²=0.95, p=0.01), as shown in Table 1. This 58% increase between the “mobile adapter” arch stiffness and the “rigid lever” arch stiffness implies different or changing mechanisms responsible for maintaining the arch. It has been suggested that midtarsal joint locking or changes in active
musculature could be responsible for this change. The AS\textsubscript{1} values were similar to plantar fascia stiffness (170±45 N/mm) calculated in vivo using fluoroscopy during the initial tension-elongation curve of slow walking [1]. The large difference between AS\textsubscript{1} and AS\textsubscript{2} also implies that calculating a single value for dynamic arch stiffness may mask some of the physiological processes taking place during running. After the run the mean AS\textsubscript{1} arch stiffness was reduced to 148.2±65.2 N/mm ($r^2=0.73$, $p=0.60$) and the mean AS\textsubscript{2} arch stiffness was reduced to 228.6±69.7 N/mm ($r^2=0.96$, $p=0.18$). Because of the large standard deviations, neither difference reached significance but AS\textsubscript{2} showed a trend toward decreased stiffness after the run. If the two arch stiffnesses are controlled by different mechanisms, it might be expected that the stiffness that relies more on active musculature would be more affected by prolonged use. For example, EMG data show posterior tibialis and the triceps surae muscles are more active during the second half of stance phase [2].

**CONCLUSIONS**

The arch of the foot is substantially stiffer during the propulsive phase of the running cycle compared to earlier stages. This lends support to the notion that the foot transforms from a mobile adapter to a rigid lever and thus optimizes its function to the requirements of gait. However, there was no evidence to suggest these functions were impaired after a hard run. Further research will examine the elements responsible for these stiffness values and the role that the shoe plays in maintaining the function of the arch.

**REFERENCES**


Table 1: AS\textsubscript{1} and AS\textsubscript{2} stiffness values before and after a run.

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<tr>
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<th>Before Run</th>
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<tr>
<td>AS\textsubscript{1} Stiffness (N/mm)</td>
<td>153.7±56.5</td>
<td>148.2±65.2</td>
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<tr>
<td>AS\textsubscript{2} Stiffness (N/mm)</td>
<td>241.0±90.5</td>
<td>228.6±69.7</td>
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