QUASI-LINEAR VISCOELASTIC PROPERTIES OF THE PLANTAR SOFT TISSUE IN COMPRESSION

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INTRODUCTION

Mechanical testing of the plantar soft tissue has consisted of primarily structural heel pad testing.[1-4] One group studied material properties and demonstrated that the subcalcaneal tissue is homogeneous.[5] However, there has been little research on other areas, and temperature, age, and vascular status are often not accounted for. The purpose of this study was to model the relaxation behavior of the plantar soft tissue the using quasi-linear viscoelastic (QLV) theory[6] at six locations: the subcalcaneal, subhallucal, lateral submidfoot and the first, third and fifth submetatarsal.

METHODS

Specimens were obtained from ten fresh frozen feet (36 ± 8.7 years, 798 ± 131 N) from seven non-diabetic donors. The plantar soft tissue was removed as 2 cm x 2 cm blocks without skin. The specimen was placed between two aluminum platens in a materials testing machine with an environmental chamber. The top platen was lowered until a force of 0.5 N was detected. The distance between the platens was the initial specimen thickness. Hot moist air was circulated to keep the specimen at 35˚ C and near 100% humidity. The target loading level for the tissue was based on ground reaction force data.[7] In load control, the specimen underwent ten 1Hz sine waves from 10 N to the target load. The displacement at the target load was noted. Using displacement control, a stress relaxation test was performed. In this test, the tissue was compressed to the noted displacement in 0.1 s and held at a constant strain for 300 s. The relaxation curves were normalized by the peak force value. The normalized curves were fit to the QLV with a non-linear least squares regression. An analysis of variance determined if the fit parameters differed across areas.

RESULTS

The long term relaxation constant, τ_2, was significantly larger for the subcalcaneal than the other areas except for the fifth submetatarsal (Table 1). No significant differences were found for the other parameters, including the short term time constant, τ_1, the amplitude of the viscous damping, c, and the elastic constants A and B. However, the two areas, the lateral submidfoot and the third submetatarsal, with the largest c also experienced the most relaxation (Figure 1).

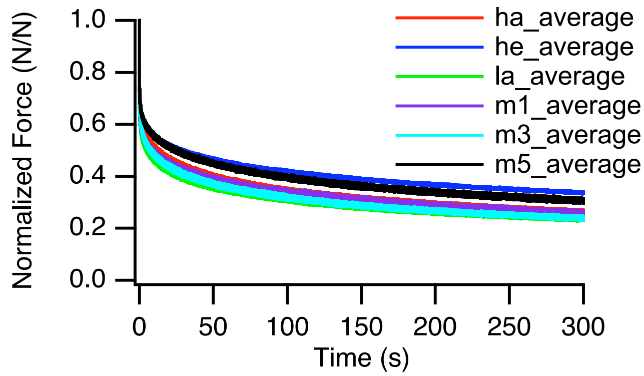

Figure 1: The average relaxation curves for the six areas.

DISCUSSION

These data indicate that some differences in the relaxation properties exist between certain areas of the foot. In particular, the large values of τ_2 seen for the calcaneus and fifth metatarsal indicate that these areas require more time to achieve steady state. The curve fits were sensitive to the initial guesses. However, we did use the same initial guesses for all specimens in each area. Also, the τ_2 obtained were greater than the length of the experiment, indicating that the experiment was terminated before steady state was achieved. Therefore in future testing, the specimen should be held at the maximum strain longer than 300 s. It should be noted that other than τ_2, there were no differences in the relaxation properties of the different areas. This has implications for computational foot models that incorporate the plantar soft tissue.

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Table 1: The QLV parameters for each of the six soft tissue locations.

area	A (N)	B (mm/mm)	c (s)	τ_1 (s)	τ_2 (s)
Subhallucal (ha)	19.88 (17.74)	9.24 (7.34)	0.848 (0.253)	0.004 (0.012)	8930 (9390)
Subcalcaneal (he)	14.84 (12.83)	87.74 (213.9)	0.523 (0.189)	0.019 (0.054)	20170 (15060)
lateral submidfoot (la)	3.75 (7.10)	53.93 (58.49)	1.028 (0.950)	0.00012 (0.0002)	6810 (7280)
first submetatarsal (m1)	16.98 (15.76)	87.26 (131.9)	0.685 (0.309)	0.005 (0.011)	5360 (2540)
third submetatarsal (m3)	14.66 (17.94)	107.3 (262.9)	0.926 (0.397)	0.005 (0.008)	7840 (8480)
fifth submetatarsal (m5)	11.47 (10.93)	13.42 (10.18)	0.814 (0.286)	0.019 (0.031)	15360 (12090)
p-value	0.21	0.74	0.43	0.53	0.035 [a]

[a] The subcalcaneal tissue was greater than all areas except the fifth submetatarsal.