A COMPARISON OF IN VIVO LOCAL METATARSAL DEFORMATION WEARING TWO DIFFERENT MILITARY BOOTS

A. Arndt, P. Westblad, I. Ekenman and A. Lundberg
Dept. of Orthopedic Surgery, Huddinge University Hospital, 141 86 Huddinge, Sweden

INTRODUCTION

The introduction of a new boot (model M90) issued to military recruits in Sweden has been accompanied by a dramatic increase in second metatarsal (MTII) stress fractures. Fatigue of the plantar musculature, especially the long flexors, has been implied in increased metatarsal loading during long marches or distance running. In this study in vivo determination of local bone deformation was combined with the measurement of muscle activity in an attempt to determine variation in metatarsal loading when wearing two different military boots (M90 and the previously issued model M59). The aim was to provide data for describing the etiology of metatarsal stress fractures.

REVIEW AND THEORY

Strain gauge instrumented staples have previously been successfully applied for measuring local bone deformation in human tibiae (Ekenman et al., 1998). Their applicability to considerably less robust bones such as the human MTII was ascertained in a previous in vitro study with chicken tibiae. The linearity of the staple measured signal relative to surface deformation was $R^2 = 0.994 \pm 0.002$ (Arndt et al., submitted). Human metatarsal loads have been presented before. The studies concerned utilized biomechanical modeling (Gross and Bunch, 1989) or in vitro measurements (Sharkey et al., 1995) and were therefore, restricted in the presentation of temporal deformation patterns or accurate differences between experimental treatments. These two studies reported dorsal MTII compression strains of approximately 6600 $\mu$ε in distance running and 1700 $\mu$ε in a simulation of stance phase respectively. This discrepancy appears large despite the different conditions investigated and direct in vivo determination of loading was seen as a means of illuminating the precise range in which loading occurs. The hypothesis was that greater local metatarsal strain would be measured when wearing model M90 than M59, especially after a fatigue treatment and that any increase in strain was dependent upon fatigue parameters.

PROCEDURES

A titanium staple instrumented with a uniaxial strain gauge was inserted in the dorsal aspect of the MTII under local anesthetic. One subject walked on a treadmill for 30 minutes wearing a 20 kg backpack. Three data recordings (15 s, 11 – 13 steps) were taken before and two after this treatment in both boot models. Wire electrode electromyography (EMG) was employed for measuring flexor digitorum longus (FDL) activity. Static maximum voluntary contractions (MVC) were performed prior to the walking protocol for subsequent calculation of muscle activation amplitude (%MVC). EMG and strain gauge signals were synchronized and sampled at 1000 Hz. EMG analysis included calculation of mean power frequency (MPF) and amplitude (%MVC). Statistical significance ($\alpha \leq 0.05$) of differences between boots and before and after 30 minutes walking were tested for with a one way analysis of variance (ANOVA) with post hoc Tukey Kramer HSD analysis.
RESULTS

Temporal deformation patterns when wearing military boots differed from barefoot in that a double compression peak was seen during the stance phase as compared to only one barefoot (Arndt et al., 1999). The first of these peaks (comp. 1) was of longer duration (approx. 380 ms) whereas the second (comp. 2; approx. 150 ms) during later stance was shorter and of lesser amplitude (figure 1A). Comp.1 pre-treatment was significantly greater in the M59 boot. After 30 minutes walking it had, however, increased significantly in the M90 but decreased for the M59 (not significant). Fatigue has previously been shown to increase EMG signal amplitude and decrease its frequency component. After 30 minutes walking FDL exhibited significantly increased signal amplitude in both boot models and this difference was greater in the M90. No significant changes were seen in MPF (figure 1B).

Figure 1. A: Dorsal MTII strain measured in two boots before and after 30 minutes treadmill walking. B: EMG amplitude and frequency changes recorded in the flexor digitorum longus. Stars indicate statistically significant differences.

DISCUSSION

The results showed a significant increase in the major compression peak (comp. 1) in the M90 boots after walking only 30 minutes with a backpack whereas a decrease in this parameter was recorded in the M59 boots. The new M90 boot is generally regarded as providing the wearer greater comfort, partly due to a more flexible outer sole underneath the metatarsal-phalangeal joints. An explanation for the greater loading is that the stiffer sole of the M59 boots assists the plantar structures of the foot in limiting dorsal metatarsal bending moments. The fact that metatarsal loading in the M59 was significantly greater prior to fatigue, however, indicated that the stiffer sole had no role in directly resisting dorsal bone deformation. The support provided by the sole appears significant only with fatigue of the plantar musculature.

Basic data describing MTII deformation while walking in military boots was presented together with a theory for the greater incidence of stress fractures in certain models.

REFERENCES

Arndt A. et al. Submitted, J. Biomechanics.