INTRODUCTION:
When subjected to simultaneous axial and torsional loading, it has been shown that human cortical bone fails in fatigue according to the phase angle between different types of combined loading (1). Through anisotropic analysis (2) of the actual in-vivo loading patterns of human tibial cortical bone during specific types of loading situations, the axial and torsional loading waveforms can be analyzed to determine the phase angle between the axial and torsional loading; which can be then analyzed as a function of type of activity. The objective of this study was to create a set of computer functions in a matrix manipulation environment that could filter, analyze and report many different aspects of loads and deformations experienced by bone during everyday activities, and Furthermore, to determine if particular athletic activities would consistently affect the phase angle between axial and torsional loading, and therefore, probability of fatigue failure of the human tibia.

METHODS:
Data from one adult male subject was obtained from researchers in Israel, from a study conducted at the Hadassah University Hospital and Hebrew University in Jerusalem (3); the experimental protocol was approved by the Helsinki Committee on Human Experimentation of Hadassah University Hospital. Strain levels of the medial tibial cortex at midshaft were measured by an unstacked, 45° strain gauge rosette was mounted in-vivo, and data recorded by a beltpack recorder (sampling rate 400 Hz, amplification factor 500). In the original study, the strain data were analyzed to reveal principal strains (the maximum and minimum strain experienced at the location of the strain gauge). The focus of the current study was to use the existing raw dataset from the previous study and perform a complete anisotropic strain analysis (2, 4) in order to obtain the normal stresses in the bone, which would reveal the actual loading patterns experienced by the tibia in an attempt to isolate a consistent phase angle between the axial and torsional loading on the tibia. All data analysis was performed in the MatLab programming environment (The MathWorks, Inc.); functions were created to handle each individual step in the data analysis procedure. Initially, data was filtered by a second-order Butterworth filter that created a 6dB amplitude rolloff at 100 Hz; these filter parameters were chosen to eliminate as much noise as possible while maintaining the integrity of the data. After filtering was performed, at this point, normal strains, principal strains, and normal stresses were determined. The magnitude of the axial compressive stress was then plotted for each dataset versus magnitude of torsional stress, and each individual cycle was measured to determine wavelength. The offset between the axial load peak and the torsional load peak was also measured, and these two values manipulated to determine phase angle. This phase angle for each cycle was input into Excel (Microsoft, Inc.) and a moving-point average analysis was performed on the data to determine if the phase angle tended to converge to a certain point.

RESULTS:
The analysis of the datasets that were recorded during walking with a pack in light military boots demonstrate a consistent phase angle for each individual activity, and a significant difference depending upon the incline encountered during the activity. Within each activity, principal strains and stresses were largely the same, but dependent upon incline of ground surface during activity, the phase angle varies considerably. Ten cycles from each dataset were analyzed; results shown in Fig. 1 clearly indicate that walking on level ground shows the least probability for fatigue fracture when considering only phase angle; the difference between axial and torsional peaks for this activity was ~180°; when walking uphill, the phase angle tended to converge to ~77°, and when walking downhill, to ~107°. When phase angle was analyzed as a function of various orthotic devices installed in the footwear (Fig.2), a slight difference was noted; the phase angle of the control (no orthotic) and the Zohar orthotic device was ~11°, however, the kinetic wedge was shown to converge to ~8°; this was not considered significant for this study.

DISCUSSION:
A very efficient and functional computer program for strain analysis was developed during the course of this study, and will hopefully be used in the future for performing analyses of similar nature. The principal stresses that were determined in this study may also be used in the future to calibrate in-vitro testing apparatus. Additionally, the large variability noted in the phase angle between certain types of activities and the consistency of phase angle in each particular dataset is of note. When taken with the knowledge that particular activities exhibit very similar peak loading values, but considerably different phase angle between loading, this could indicate that phase angle may play a more significant role in fatigue fracture. The results shown in Fig. 2, although not considered significant in this study, indicate that phase angle should be considered during the design phase of orthotic devices, and perhaps devices could be tuned to correct for dangerous phase angles known to exist during certain types of athletic activity that demonstrate a high incidence of fatigue fracture.

REFERENCES:

AFFILIATED INSTITUTIONS FOR CO-AUTHORS:
**Hadassah University Hospital, Hebrew University Medical Center

ACKNOWLEDGEMENTS: The Whitaker Foundation (Grant: Multiaxial Fatigue Characteristics of Aging Bone: Vashishth)

50th Annual Meeting of the Orthopaedic Research Society
Poster No: 0517