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This collaborative project involves the Johns Hopkins University in Baltimore and the Naval Health Research Center in San Diego; COL Bruce Jones a renowned US Army expert on overuse injury is a consultant to the project. The study involves lower limb bone structural measurements using a dual energy x-ray absorptiometry (DEXA) system, and a set of anthropometric measurements on recruits beginning training. Measurements from fracture cases occuring during training will be compared with non fracture cases. As of September of 1996, a total of 659 female Marine Corps Recruits from Parris Island Marine Recruit Training Center were enrolled. The last group will have completed training by December 1996 although assessment may not be completed before the end of January 1997. A subset of 175 females were scanned a second time at the end of the 12 week training period to ascertain the effect of training on bone geometry. The DEXA data will also be employed to devise an objective measurement of muscle strength at the mid thigh. Although data collection except for stress fracture ascertainment is nearly complete, no conclusions can be made until all data are checkeced for accuracy and completeness.

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FOREWORD

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Thomas Bach 10-10-96

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INTRODUCTION

Stress fractures cause significant morbidity during recruit training, particularly for elite programs requiring intense physical conditioning such as the US Marine Corps[1,2,3,4]. Estimates of the incidence of stress fractures among female military trainees range from as high as 34% to as low as 1.1%[5,6,7,8]. Data from Marine Corps Parris Island[9] indicate that women suffer lower extremity stress fractures at a rate of 3.8% a rate comparable to that of males[10]. More recent data from an associated study indicates that the stress fracture rate in the current female cohort is about 5%[a]. The primary fracture site is in the metatarsals, although pelvic and femoral stress fractures constituted more than half of the total (ibid.).

The impact of stress fractures on training and on operational readiness is significant. While stress fracture is not the most prevalent injury among recruit populations, the cost of each occurrence is high. Recent data on male recruits at MCRD San Diego show that with an incidence rate of 3.7%, lower extremity stress fractures cause a loss in training time of 35-69 days and costs on the order of $4 million annually for that site alone.[11]. Although the numbers of female recruits is smaller, the number of costly above-the-knee fractures in females is far greater.

Stress fractures, which predominantly occur in the lower extremity and pelvic girdle, are believed to result from structural failure in the bone caused by repetitive weight bearing loads. Weight bearing under training regimens subjects bones of the lower limbs to repetitive axial compression, torsion and bending stresses[12]. Within a bone subject to a given load, stress magnitudes are determined by bone structural geometry, while the bone's ability to resist these stresses is defined by bone material properties.[13,14] Since bone material properties are much less variable than structural geometry, it is likely that most of the individual differences in bone strength can be explained by geometry[15]. Moreover there is evidence that bone material properties do not vary significantly with age as was previously believed[16] . For a given long bone, the most important geometric properties are the cross-sectional area (CSA) and for bending in a plane, the cross-sectional moment of inertia (CSMI). These structural properties in the long bones of the lower extremity are known to vary with age and sex in the human. For example, previous work suggests that sex differences in elderly fracture rates may relate to the ability of aging bone to alter the CSMI to compensate for increased mechanical stresses due to bone loss in osteoporosis[17]. There is also evidence that bone is structurally remodeled to minimize stresses in limbs subjected to increased loads over shorter time scales; moreover these changes are evident in the cross-sectional properties[18]. The implication for younger populations is that bone can be strengthened by rigorous training. Unfortunately, information regarding the rates and magnitudes of such change and in the factors influencing such change in the human are scanty. The current project includes an assessment of geometric changes in the lower limbs of female Marine Corps recruits. Such data should have significant implications in the design of future recruit training programs as well as in the design of remediation regimens for those with structurally weak bones.

BODY

Materials and Methods

This project involves the acquisition of data to support two separate hypotheses. The first is that those structural geometry properties measured in the lower limb that were found to be associated with lower limb stress fractures in male Marine Corps recruits[19(1)], will exhibit a similar association in female recruits. The second hypothesis is that the intense training regimen in female Marine Corps recruits will produce changes in the structural geometry of the lower limb bones that are indicative of improved bone strength. To support the first hypothesis, a cohort of female recruit volunteers were given a consent form during the first week of recruit training and then

[a] Shaffer RA, Brodine S et al. Predictive Factors for Stress Fracture Susceptibility in Female Marine Recruits, Draft report Personal communication 10-9-96.

administered a questionnaire soliciting general background information issues (diet, exercise, menstrual, smoking, skeletal injury, history etc.). A subset of these recruits were administered a second informed consent to participate in the part of the study including DEXA scans and anthropometric measurements. A randomly selected sample of volunteers was selected for further measurements. Measurements included height, weight, neck waist and hip girths, thigh and calf girths as well as the lengths of the upper and lower right leg, the girths of the pelvis between the iliac crests, the hips between the greater trochanters, and the knee at the level of the femoral condyles. Subjects were then scanned with a conventional dual energy x-ray absorptiometry (DEXA) scanner at both the mid shaft of the right femur and at the distal third of the lower right leg. The entire cohort of cohort was followed to ascertain the incidence of stress fractures and other musculoskeletal injuries. Enrollment included the administration of a questionnaire on general background issues (diet, exercise, menstrual, smoking, skeletal injury, history etc.) administered for our colleagues at the Naval Health Research Center in San Diego. The questionnaire was followed by a solicitation to volunteer as a participant in a study involving further measurements. Informed consent was obtained on all study participants. A random subset of those providing informed consent was selected for measurements. To address the second hypothesis, a subset of recruits receiving measurements at the beginning of training, were re-scanned during the last week of training, and those anthropometric measurements (weight and girths) likely to change were also repeated. In this part of the study the effect of the standard training regimen on the normal skeleton is being evaluated hence all recruits with sufficient injury to cause interruption of training, or any recruits undergoing more than 12 weeks of training were excluded. A third part of the study involves the use of relative lean muscle mass measurements provided by the DEXA scanner. We are exploring the use of these measurements as indices of fitness by comparing them with the initial strength test scores recorded for recruits during the initial evaluation of recruits.

CONCLUSIONS

As of September 15, 1996 a total of 659 recruits were enrolled in the measurement procedure, although approximately 1500 had received questionnaires. For the accrual in the second part of the study, a total of 175 recruits were re-scanned at the end of training. During the final day of scanning, the DEXA scanner experienced a major failure which is yet to be repaired. Sufficient data has been acquired for both parts of the study, however, for technical reasons the precision study was not yet done. We have not yet made the decision whether to proceed with the scanner repair and are looking into alternative ways of addressing the precision issue.

The measurement of the structural geometry from the DEXA data involves a program written in our laboratory, hence scan data are transferred from Parris Island for this stage. At this point all data have been transferred and the structural measurements have been computed. Anthropometric variables have also been coded into computer format and the collating of all variables and the correction of entries is under way.

Although it is possible to make some preliminary conclusions based on incomplete data, we believe that this would be premature since data “cleaning” for coding and analysis errors is not finished. Moreover follow-up on subjects for stress fracture assessment will probably not be complete until mid January. We suspect that we will alter the focus somewhat from the original work to include attempts to derive a biomechanical explanation for the greater above-the-knee stress fracture rate in females compared to males.

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