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**INJURY REDUCTION EFFECTIVENESS
OF PRESCRIBING RUNNING SHOES
BASED ON FOOT SHAPE
IN AIR FORCE BASIC MILTARY TRAINING**

**U.S. Army Center for Health Promotion and Preventive Medicine
Aberdeen Proving Ground, MD**

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14. ABSTRACT
In response to a request from the Military Training Task Force of the Defense Safety Oversight Council, this study examined whether prescribing running shoes based on the shape of the plantar surface influenced injury risk in Air Force Basic Military Training (BMT). After foot examinations, BMT recruits in an experimental group (E, n=1,042 men, 375 women) were prescribed motion control, stability, or cushioned shoes for plantar shapes indicative of low, medium, or high arches, respectively. A control group (C, n=913 men, 346 women) received a stability shoe regardless of plantar shape. Injuries during BMT were determined from outpatient visits provided by the Army Medical Surveillance Activity (now the Armed Forces Health Surveillance Center). Other known injury risk factors (e.g., fitness, smoking) were obtained from a questionnaire, existing databases or BMT units. Multivariate Cox regression controlling for other risk factors showed little difference between the E and C groups among men (hazard ratio(E/C)=1.11, 95% confidence interval=0.89–1.38) or women (hazard ratio(E/C)=1.14, 95% confidence interval = 0.85–1.55). This prospective study demonstrated that prescribing shoes on the basis of the shape of the plantar foot surface had little influence on injury risk in BMT even after control of other injury risk factors.

15. SUBJECT TERMS: Physical fitness, physical activity, height, weight, body mass index age, arch height, smoking, education, race, marital status, prior injuries, menstrual history, pregnancy, birth control, push-ups, sit-ups, 1.5 mile run.

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EXECUTIVE SUMMARY
USACHPPM REPORT NO. 12-MA-05SBA-08A
INJURY REDUCTION EFFECTIVENESS OF PRESCRIBING RUNNING SHOES BASED ON FOOT SHAPE IN AIR FORCE BASIC MILTARY TRAINING

1. INTRODUCTION AND PURPOSE.

a. In 2003, the Secretary of Defense directed the Department of Defense to reduce preventable mishaps or injuries by 50%. The Under Secretary of Defense for Personnel and Readiness responded by establishing the Defense Safety Oversight Council (DSOC), which chartered nine task forces to develop recommendations to reduce preventable injuries. One of these, the Military Training Task Force (MTTF), worked to decrease injuries during military training activities. Each year the MTTF prioritized a number of projects directed at training-related injury reduction. In 2005, the MTTF ranked military physical training footwear prescription and trainee fitness fifth out of 21 projects.

b. The practice at the time of this study in the United State Air Force was to provide a single running shoe to recruits entering Basic Military Training (BMT). However, in Army and Marine basic training new recruits are prescribed running shoes based on the amount of foot surface contacting the floor (i.e., plantar shape). The plantar shape during weight-bearing is presumed to reflect the longitudinal foot arch height. Shoe manufacturers market three classes of running shoes designed for individuals with high, normal, and low arches: cushion, stability, and motion control, respectively. These shoes presumably reduce injuries by compensating for hypothetical differences in running mechanics. The major purpose of this study was to determine whether or not injury risk can be reduced by prescribing running shoes based on the static weight-bearing plantar foot shape. Secondary purposes were to 1) examine the association between the shape of the plantar foot surface and actual arch height, 2) examine the relationship between arch height and injuries, and 3) examine risk factors for injuries in BMT.

2. METHODS.

a. Participants were male and female volunteers engaged in BMT at Lackland Air Force Base, Texas. Just prior to BMT, subjects were administered a questionnaire that asked about tobacco use, physical activity, injury history, and (for women) menstrual history. To determine the shape of the plantar surface of the foot (plantar shape), the barefoot subject mounted an illuminated device that reflected the underside of the foot. Two observers made independent determinations of the plantar shape as high, normal, or low based on templates: more area in the middle third of the plantar surface indicated a low plantar shape and less area a high plantar shape. After the plantar shape determinations, subjects' longitudinal foot arch heights were measured with a digital caliper as the distance from standing surface to the inferior medial border of the navicular tuberosity.

b. Subjects were randomized into either an experimental (E) or control (C) group. The C group subjects received a New Balance 498 (stability shoe) regardless of plantar shape. The E group subjects received a shoe based on their plantar shape: if the E group subject had a low plantar shape, a New Balance 587 (motion control shoe) was provided; if the E group subject had a high plantar shape, a New Balance 755 (cushion shoe) was provided; if the E group subject had a normal plantar shape, a New Balance 498 (stability shoe) was provided.

c. Injury data was obtained from the Defense Medical Surveillance System (DMSS, now the Armed Forces Health Surveillance Center). The DMSS regularly incorporates data on ambulatory (outpatient) encounters that occur within military treatment facilities (MTFs) as well as those that occur outside the MTFs but are paid for by DOD. The DMSS provided visit dates and ICD-9 codes for all outpatient medical visits within the BMT timeframe of each subject. Injuries were determined using standard ICD-9 codes. Additional data obtained included attrition from training, physical fitness test scores (push-ups, crunches, and 1.5-mile run), physical characteristics (height, weight, body mass index, abdominal circumference), and demographics (date of birth, component, educational level, marital status, race).

3. RESULTS.

a. There were 2,167 men and 854 women who volunteered for the study during their inprocessing just prior to officially beginning BMT. Subjects were excluded from the analysis if 1) they did not actually enter BMT for medical or administrative reasons or 2) they were recycled in training (the recycle database did not have the day the subject was recycled so the time at risk could not be determined). The final cohort considered for analysis consisted of 1,979 men and 723 women.

b. Injury rates during the 6-week BMT period differed little between the E and the C groups among the men (E=7.0, C=6.4 injuries/1000 person days, p=0.30) or the women (E=13.0, C=10.9 injuries/1000 person-days, p=0.11). Univariate Cox regression (a survival analysis technique) found little difference in injury risk among E and C men (hazard ratio (E/C)=1.09, 95%confidence intervals (95%CI)=0.92–1.29); however, E women tended to have higher injury risk than C women (hazard ratio (E/C)=1.23. 95%CI=1.00–1.53). In multivariate Cox regression controlling for other known injury risk factors, there was little difference in injury risk among E and C groups for either men (hazard ratio (E/C)=1.11, 95%CI=0.89–1.38) or women (hazard ratio (E/C)=1.14, 95%CI=0.85–1.55).

c. Factors significantly associated with injury risk in both men and women included slower 1.5-mile run times and cigarette smoking prior to BMT. Men were also at higher risk if they had lower body mass index, performed fewer push-ups or abdominal crunches, were of Black race, or were of "other" marital status (i.e., divorced, widowed, or separated). Women were also at higher injury risk if they had higher body mass index, low educational status (not high school graduate), were of White or Black race (relative to Asian), or had run less frequently or for a shorter period of time prior to BMT.

d. Individuals with lower measured foot arch heights (lower 20% of cases) had higher injury risk than those with normal arch heights (middle 60% of cases) or high arch heights (higher 20% of cases). For the right foot, low-arched men had injury risk 1.43 (95%CI=1.15–1.78) higher than those with normal arch heights; low-arched women had injury risk 1.41 (95%CI=1.07–1.89) higher than those with normal arch heights.

e. Plantar shapes of low to normal to high had mean arch height in the expected direction. For the right foot arch of the men, plantar shapes rated as low, normal, and high had average±standard deviation arch heights (cm) of 27.6±5.7, 36.0±7.3, and 38.7±7.6, respectively ($p<0.01$); for women, these values were 25.2±5.7, 33.2±6.4 and 36.1±6.2, respectively ($p<0.01$). Arch heights were separated into the percentile distributions found in the plantar shapes and a "match" was defined as an arch height percentile that matched the low, normal, and high plantar shape percentile. Overall, arch height percentiles were matched to plantar shape percentiles only 64% of the time. Normal plantar shapes had the largest numbers of matches (over 75%) with high and low plantar shapes matching only 24% to 49% of the time, respectively.

4. **CONCLUSIONS.**

a. This prospective study demonstrated that prescribing running shoes based on the static weight-bearing plantar foot surface shape had little influence on injury risk in BMT, after controlling for other injury risk factors. There was little difference in injury risk among those who were prescribed a shoe (motion control, stability, or cushion) based on plantar shape and those who received a stability shoe regardless of plantar shape.

b. Individuals in the lower 20th percentile of arch heights tended to be at higher risk of injury during BMT.

c. Plantar foot shapes visually judged as low, normal, and high had progressively higher average arch heights. Despite this, there were a considerable number of mismatches when plantar shapes were matched with corresponding percentiles of arch heights. Arch heights matched corresponding percentiles of measured plantar shapes only about 64% of the time, overall.

d. This is the first study examining injury risk factors in US Air Force BMT. In consonance with previous Army data and some Marine data, injury risk was higher among men and women who were of lower physical fitness and/or who were cigarette smokers. Men were also at higher risk if they had lower body mass index, were of Black race, or were of “other” marital status (divorced, widowed, or separated). Women were also at higher injury risk if they had higher body mass index, low educational status (not high school graduate), were of White or Black race (relative to Asian), or had run less frequently or for a shorter period of time prior to BMT.

5. RECOMMENDATION. If the goal is injury prevention, it is not necessary to prescribe running shoes to BMT recruits based on a visual inspection of the static, weight-bearing plantar shape. Prescribing running shoes to BMT recruits on this basis was no more protective against injury than issuing a single shoe regardless of plantar shape. Other procedures need to be considered to prevent injuries in recruits with lower arch heights, since they appear to be at higher injury risk. It is still recommended that recruits receive a new shoe on entry to BMT, since older shoes have previously been shown to be associated with increase injury risk.

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1. REFERENCES. Appendix A contains the scientific/technical references used in this report.

2. INTRODUCTION AND PURPOSE.

a. In 2003, the Secretary of Defense directed the Department of Defense to reduce preventable mishaps or injuries by 50%. In 2006, the goal became to reduce preventable mishaps or injuries by 75%. The Under Secretary of Defense for Personnel and Readiness responded to the directive by establishing the Defense Safety Oversight Council (DSOC), which chartered nine task forces to develop recommendations for policies, programs, and investments to reduce preventable injuries and accidents. One of these task forces, the Military Training Task Force (MTTF), sought to validate solutions to reduce the risk of injury during military training activities. Each year the MTTF prioritized a number of projects directed at training-related injury reduction. In 2005, the MTTF ranked military physical training footwear prescription and trainee fitness fifth out of 21 projects. The chairman of the MTTF requested the assistance of the United States (US) Army Center for Preventive Medicine (CHPPM) and the Naval Health Research Center in organizing a triservice effort to address footwear prescription.

b. The practice in the United State Air Force (USAF) at the time of the study was to provide a single running shoe to recruits entering Basic Military Training (BMT). However, in Army and Marine basic training new recruits were prescribed running shoes based on the amount of foot surface contacting the floor (i.e., the shape of the plantar foot surface). The plantar foot shape during weight-bearing is presumed to reflect foot arch height. Shoe manufacturers market three classes of running shoes designed for individuals with high, normal, and low arches: cushion, stability, and motion control, respectively. These shoes presumably reduce injuries by compensating for presumed differences in running mechanics (1). At the time this study was conceived there was insufficient evidence in the scientific literature to determine whether this strategy does, in fact, reduce injuries (2).

c. The major purpose of this study was to determine whether or not injury risk can be reduced by prescribing running shoes based on the static weight-bearing plantar foot shape in USAF BMT. There were three secondary purposes to this study. As noted above, the shape of the plantar foot surface is assumed to reflect foot arch height, but this assumption has not been examined. Thus, a secondary purpose was to examine the association between the shape of the plantar foot surface and arch height. A few studies have suggested that a relationship may exist between injuries and foot arch height (3, 4). Thus, another secondary purpose was to examine the relationship between arch height and injuries. Finally, this study also presents the opportunity to see if fitness and lifestyle factors that are known to increase injury risk in Army and Marine Corps basic training (5-7) also increase injury risk in Air Force BMT. One previous study of BMT (8) examined injury rates but did not investigate injury risk factors.

3. AUTHORITY.

a. Under Army Regulation 40-5 (9), the US Army Center for Health Promotion and Preventive Medicine (CHPPM) is responsible for providing epidemiological consultation services upon request. This project was initiated by the MTTF of the DSOC and a letter of request is in Appendix B. The studies recruited Service Members participating in basic training in the Army, Air Force, and Navy. Personnel from Lackland Air Force Base collected BMT recruit data but did not have the local expertise to analyze the data. At the request of the Chief, Trainee Health Preventive Medicine, Wilford Hall Medical Center, Lackland Air Force Base, CHPPM agreed to assist with design implementation, analyze the data, and complete the scientific report on the project.

b. Employing the criteria of the Council of the State and Territorial Epidemiologists (10), it was determined that this project constituted research. Thus, a research protocol was submitted to the Wilford Hall Medical Center Institutional Review Board (IRB) at Lackland Air Force Base, Texas. The IRB approved the research protocol and the approval is in Appendix C.

4. BACKGROUND. Popular running magazines, shoe companies and other publications (1, 11-15) suggest that the shape of the plantar surface of the foot can be used as an indication of the height of the longitudinal foot arch and that this can be used to select appropriate types of running shoes. Individuals with low arches are presumed to have disproportionate foot flexibility that allows the foot to pronate excessively during the stance phase of running. Motion control shoes are prescribed for those with low arches to presumably control this excessive pronation. Individuals with high arches are assumed to have rigid or inflexible feet that underpronate and impact the ground with high force. Cushioned shoes are designed for those with high arches to presumably allow more pronation and provide cushioning to reduce ground impact forces. Individuals with average arch heights are assumed to impact the ground with less force and to have an appropriate amount of pronation during the stance phase of running. Stability shoes are designed for those with average arches and these shoes have moderate cushioning and motion control characteristics (1).

a. <u>Gait Mechanics and Characteristics of Running Shoes.</u>

(1) The categorization of running shoes into motion control, stability, and cushioning shoes rests on two assumptions: 1) that individuals with high and low foot arch heights have the gait mechanics described above, and 2) that particular shoe characteristics can adjust or compensate for these gait differences to more closely conform to those of individuals with more average arch heights. With regard to the first assumption, when previously injured or

symptomatic runners with low and high arches were tested using the same shoes, there were differences in running kinematics. Runners with low arches tended to demonstrate more inversion/eversion and less internal tibial rotation on the talus during the stance phase of running. Runners with high arches had less inversion/eversion, more internal tibial rotation on the talus, more leg stiffness, higher initial ground impact forces, and a higher rate of initial force development on ground impact (16-18). On the other hand, when nonsymptomatic high- and low-arched runners or walkers were examined, there were few arch-related differences in rearfoot motion or impact forces (19-22). Thus, gait differences associated with foot type may be more applicable to symptomatic and previously injured individuals but less applicable to those who are not experiencing symptoms or who have not been previously injured.

(2) The second assumption is that particular shoe characteristics can adjust the gait mechanics of high- and low-arched individuals to more closely conform to that of individuals with average arch heights. Motion control shoes attempt to attenuate excessive rearfoot motion; cushioned shoes attempt to alleviate higher impact forces while allowing more rearfoot motion. However, when high-arched or low-arched individuals ran in motion control or cushioned shoes, there was little difference in kinematics between these two foot types even during prolonged running (23, 24). The only variable to differ was the instantaneous loading rate (maximal instantaneous slope of initial force development on ground impact), which, contrary to expectation, was actually higher in the cushioned shoe (compared with the motion control shoe) when worn by the low-arched individuals. This occurred despite the fact that motion control shoes (regardless of arch type) attenuated rearfoot motion better than cushioned shoes and that cushioned shoes generally attenuated shock better than the motion control shoes (23, 24). Thus, while the shoes performed as expected, there were no differences in mechanics (other than instantaneous loading rate) between low- and high-arched individuals running in these shoes.

b. <u>Running Shoe Functions.</u> The literature suggests that running shoes should have four major functions: a) protect the foot from the external environment, b) provide traction by increasing friction, c) attenuate the shock of foot strike, d) provide motion control during the stance phase of the running cycle (25-28). The shoes should be as light as possible to minimize the energy cost of additional weight (29).

(1) **Protection of the Foot.** Protection of the foot from the external environment is an obvious shoe function. Surfaces can be hot, cold, rocky, and/or uneven. The shoe protects the plantar surface of the foot by providing a barrier to the external environment and a relatively even surface to bridge uneven ground. The shoe thus protects the foot from extremes of temperature and physical trauma such as abrasions, lacerations, and contusions.

(2) **Traction.** Another function of the shoe outsole is to increase traction. The composition of the outsole of most shoes provides a high coefficient of friction with concrete and asphalt surfaces (30). Better traction may reduce the probability of traumatic injuries from slips and falls. It may also improve running efficiency by preventing slipping and by directing

muscular effort more effectively in positioning the foot during the stance phase of running. Greater traction also provides more effective forward movement during the toe-off phase of running.

(3) **Attenuation of Shock.**

(a) Compared with bare feet, running shoes generally result in a decrease in the force of the initial impact spike and a slower initial rate of force development (31-35). Certain shoe characteristics may attenuate shock. Heel counters on shoes appear to reduce the lateral compression of the anatomical heel pad, making it a more effective shock absorber (33, 36, 37).

(b) The effect of shock-absorbing materials in the shoe is not clear. In studies where materials are placed on benches and durometers are used to measure material hardness (38), investigators find (as would be expected) that impact forces decrease as material hardness decreases (34, 39, 40)**.** On the other hand, studies involving subjects running across force platforms have shown little difference in external impact forces for different types of midsole hardnesses (34, 41-43). This is surprising since, as with bench studies, lower impact forces might be expected for softer, more compliant insoles (i.e., ethyl vinyl acetate (EVA) versus polyurethane). Several hypotheses have been advanced to explain this finding. Lake (41) suggested that this lack of difference in impact forces among midsoles of various hardnesses may not be surprising since the force platform measures the vertical ground reaction forces, and these forces reflect the acceleration of the total body's center of mass. Average measures may mask large changes occurring in the legs. Nigg et al. (42) suggested that changes in midsole hardness may result in a redistribution of loads across the foot. They found that with harder midsoles subjects landed on more lateral portions of the shoe and ankle pronation velocities were greater. With greater velocity and more deceleration distance, the initial impact force decreased. Thus, with different midsole hardnesses subjects adjusted their foot strike to achieve similar external impact forces. Studies performed on different types of running surfaces show that runners increase their leg stiffness when running on soft, compliant surfaces and decrease their leg stiffness when running on harder surfaces (44, 45)**.** Yet, a recent study examining two-dimensional sagittal plane kinematics showed no differences in leg stiffness between the two shoes with different cushioning properties (impact forces were not reported) (46). Thus, the effects of midsole hardness on impact forces are not clear at this point. Studies using shoes with different midsole hardnesses and employing three-dimensional kinematics with force platforms are necessary.

(c) Robbins and Gouw (47) have challenged the assumption that shock absorption should be a characteristic of running shoes. They hypothesize that normal plantar tactile stimulus during running results in adaptations that reduce impact forces and presumably reduce the likelihood of injury. These impact-moderating behaviors include greater use of intrinsic foot shock absorption, greater knee and hip flexion, and a decrease in the height of the leg drop just prior to the stance phase of running. They propose that plantar feedback is optimal between bare feet and natural surfaces and that the cushioning in running shoes attenuates plantar feedback. They showed that sufficient vertical and horizontal impact forces (> 0.4 kg/cm^2) evoked higher subjective discomfort; an irregular surface further increased this discomfort. However, they did not specifically measure their hypothesized impact-moderating behavior. Further, testing was not conducted while running but rather while subjects were seated with impact loads applied by pistons to the thigh and Achilles tendon regions. Also, their subjects were not runners.

(4) **Motion Control.**

(a) There has been a good deal of research on “rearfoot control,” which can be defined as the ability of shoes to limit the amount of foot pronation after foot strike (48). For example, one early study compared two shoes: 1) a training shoe that had a multidensity midsole (EVA and polyurethane), a stiff heel counter, and a wide heel base, and 2) a racing flat that had a midsole of uniform density EVA, a softer heel counter, and a much narrower heel base. The training shoe had about 20% less total rearfoot motion (49). While studies of this type are suggestive, they do not allow isolation of specific factors that may influence rearfoot control. Fortunately, other studies have systematically manipulated shoe characteristics, and specific factors that limit foot pronation have been identified. Characteristics that have been investigated include midsole hardness, heel flare, and heel lift.

(b) Midsoles constructed of softer material resulted in greater and more rapid foot pronation than harder material (48, 50). Softer midsoles resulted in a resupination of the foot while the knee was still flexing. It was suggested that this could set up an antagonistic relationship: the resupinating foot caused an external rotational torque on the tibia, while the flexing knee imposed an internal rotational torque. Repeated cycles of these opposing torques during running could result in an overuse injury to the knee (50).

(c) The influence of heel flare (the angular distance that the midsole in the heel area protrudes from the lateral and/or medial portions of the shoe) is not clear but the inconsistent results suggest that heel flare has no systematic influence on rearfoot motion. One study found the lack of heel flare resulted in greater and more rapid total pronation (48), while other studies showed no effect (51, 52). Heel flares of 0 to 30 degrees were tested. In one study, initial joint pronation (first tenth of foot contact time) and initial pronation velocity was less with a negative (more rounded) heel flare, but total amount of pronation was not affected. Greater heel flare did not change the vertical impact forces, but did result in a later occurrence of the impact force after heel strike (51).

(d) Heel lift (a greater height in the rear of the shoe than in the front of the shoe) has been hypothesized to reduce the incidence of Achilles tendonitis by reducing forces on the Achilles tendon (53-55). However, the magnitude and time of occurrence of the maximal plantar flexion moments (a surrogate for Achilles tendon loading) were not altered by heel lifts ranging from 5 to 9.5 degrees (55). On the other hand, as heel height increased, the angular acceleration of pronation decreased (48).

(e) Medial (varus) and lateral (valgus) wedging have also been compared. Varus wedging is achieved by placing a wedged-shaped pad under the medial aspect of the heel, thus causing the calcaneus to tilt away from the midline of the body. Conversely, the same wedge placed under the lateral aspect of the heel causes the calcaneus to tilt toward the midline of the body. A 5-degree varus wedge was found to decrease foot pronation, but it also increased peak impact, rate of force development, and tibial shock (56). Thus, there are tradeoffs with wedging.

(5) **Energy Cost.** Heel counters are firm cups surrounding the calcaneus region of the foot. They reduce the energy cost of running (36), possibly by increasing mechanical stability so that less muscular force is necessary to stabilize the lower extremity. Lighter shoes also allow individuals to run at a lower energy cost. For each kilogram added to the foot, the increase in energy expenditure is 7% to 10% (57-61). This may be because, during running, the lower extremities move through a greater range of motion than other parts of the body, resulting in more mechanical work. The additional mass on the extremities calls for greater muscular force and consequently more energy expenditure.

(6) **Summary of Running Shoe Functions.** Running shoes are generally designed to protect the foot, provide traction, attenuate the impact of foot strike, control foot pronation, and lower the energy cost of locomotion. Running in shoes reduces vertical ground reaction forces (shock absorbency), compared with running barefoot, and firm heel counters appear to be a key shoe characteristic for this effect. The effect of midsole hardness is not clear, but it may be that hardness does not influence shock absorbency since runners adjust their gait to achieve a similar impact force regardless of shoe hardness. Softer midsoles result in greater and more rapid pronation than harder midsoles. Studies of heel flare are not consistent with regard to pronation. Greater heel lift decreases pronation velocity. Heel wedges trade off stability for greater ground reaction forces. Lighter running shoes and firm heel counters reduce the energy cost of running.

c. <u>Foot Arch Height and Injuries.</u>

(1) Measuring arch height is often considered useful, quantifiable information regarding foot structure, shock absorption capabilities, and movement function. However, arch height measurement can be confounded by both bone and soft-tissue variation between individuals. Static arch height measurements alone do not take into account dynamic foot flexibility, which may be related to injury (22). Nonetheless, prospective studies specifically examining arch height and injuries during military training suggest that either high foot arches (4, 62) or both high and low foot arches (3) increase injury risk.

(2) One civilian study (17) suggests that previously injured runners with high and low arches have different injury patterns. The study selected 20 individuals with high arches and

20 with extremely low arches who had previous injuries but no current injuries. Selection was based on 1.5 standard deviations above and below the mean arch height ratio. The arch height ratio was defined as the height from the floor to the dorsum (50% of foot length) divided by the foot length from the posterior calcaneus to the first metatarsal phalangeal joint. Subjects reported their previous injuries on a questionnaire. High-arched individuals were found to have more injuries to lateral parts of the lower extremities, more bony injuries (stress fractures and stress reactions), and more foot and ankle injuries. Low-arched runners had more medial lower extremity injuries, more soft tissue injuries, and more knee injuries. The researchers hypothesized that the "pronated position of the foot often associated with a planus foot places increased stress on the medial structures of the lower extremity." The higher incidence of past knee injuries in the low-arched group could have been related to a greater range in external rotation of the knee, possibly resulting in misalignment of the patellofemoral joint and thus higher stress in this area. In high-arched individuals there was increased lateral loading of the foot compared with low-arched individuals, possibly placing more stress on this area and possibly leading to more foot and ankle injuries.

(3) Clinical classification of foot arch height may be problematic. One study measured the level of agreement among six clinicians on the classification of foot types into flat, normal, or highly arched, based on observations of photographs of different angles of the feet (63). The authors concluded that there was unacceptable interclinician variability and stressed the need for more objective standards in evaluating foot arch height. The validity of clinically diagnosed arch-height measurement has also been questioned by other authors (2, 64). There can be significant discrepancies between the radiographic appearance of the foot and the external clinical measurement. One study observed several feet that appeared clinically flat, but when lateral radiographs were obtained and standard radiographic indices applied, the feet could be classified as highly arched. It may be that simple observation of arch height alone is of little predictive clinical value (2).

d. <u>Injuries and Footwear.</u>

(1) As noted above, there are a large number of biomechanical studies involving running shoes (e.g., 25-28, 33, 36, 37) and these studies frequently hypothesize that specific changes in body mechanics induced by running shoes can influence injury rates. However, the data linking shoes to actual cases of injuries are sparse. There are two case studies and several epidemiological investigations providing some evidence that ill-fitting and older shoes may result in higher injury rates. These studies are reviewed below.

(2) Wilk et al. (65) reported a case study of a 40-year old male triathlete who presented with symptoms of right foot plantar fasciitis after a triathlon. Examination of the patient's racing shoes (which differed from the training shoe) showed that the heel counter on the right shoe had a pronounced medial tilt when compared with the left shoe. This was because the heel counter had been glued onto the shoes at an incorrect angle. The investigators hypothesized that the

medial tilt resulted in excessive pronation, creating a torsional force that repeatedly overstretched the plantar fascia leading to the fasciitis. However, the authors did not actually measure the amount of foot pronation with and without the defective heel counter. Further, plantar fasciitis is a common running injury (66-68) and the problem in this case could have been caused by factors other than the shoe.

(3) Burgess and Ryan (69) reported a case study of a 26-year-old man who lost one of his running shoes and ran a 14-km race in a borrowed pair of older "tennis" shoes. He was examined two weeks later and had slight edema and marked tenderness over the lateral aspect of both shins with radiographic evidence of bilateral fibular stress fractures. Eight weeks later there was no edema or tenderness, and radiographs showed healing stress fractures with new bone formation. Compression loading tests showed that his usual running shoe absorbed twice as much energy and deformed five times as much as the "tennis" shoe.

(4) Gardner et al. (70) found that Marine Corps recruits who reported to basic training with older running shoes were more likely to experience stress fractures than those reporting with newer shoes. Recruits who indicated that their shoes were 6 months to 1 year old were 2.3 times more likely to experience a stress fracture in training than those who indicated that their shoes were less than one month old.

(5) Injuries were compared in groups of Israeli Defense Force recruits training in either 1) modified high-topped basketball shoes with soles of EVA or 2) regular combat boots with soles of molded double-density polyurethane. Experiments showed that tibial accelerations while walking on concrete were 19% lower in the basketball shoes. The group with the basketball shoes had a lower incidence of metatarsal stress fractures and overuse injuries of the foot (metatarsalgia, heel pain, arch pain). However, the overall incidence of stress fractures or all injuries was not different between groups (femoral stress fractures were slightly higher in the basketball shoe group) (71).

(6) An observational study of injuries in basketball found that players using shoes with air cells had 4.3 times the odds of ankle injury compared with players wearing other types of shoes (72).

(7) These studies present a confusing picture. There is some suggestion that older running shoes are associated with a higher likelihood of stress fractures. This was shown in Marine Corps recruit training; one of the case studies suggested an association between lower shock absorbency and stress fractures, and there is a mileage-related loss of shock absorbency in running shoes (73). However, in the Israeli recruit study, overall stress fracture rates were the same in those wearing the boot versus the more shock-absorbent basketball shoe. In the Marine Corps recruit study, recruits wore their running shoes only for morning physical training, while in the Israeli recruit study, recruits wore the basketball shoes for all training. Perhaps shock

absorbency is more important for stress fracture reduction during more intense physical activity like running where impact forces are likely to be greater.

(8) A retrospective cohort study (29) tested the effectiveness of a running shoe prescription program for reducing injuries. At Fort Drum, New York, newly arriving Soldiers had their feet examined by a physical therapist and feet were classified on the basis of observed arch height (high, medium, or low) and flexibility (normal or rigid). A category of running shoes (motion control, stability, or cushion) was then recommended on the basis of the foot examination. International Classification of Diseases, Version 9 (ICD-9) codes representing overuse-related injuries in the lower extremity or low back regions were downloaded from the local Ambulatory Data System (ADS). Denominator data were obtained from the Fort Drum (10th Mountain Division) S-1 Office (Personnel Section). Injury rates were 36.8 cases/1000 soldier-months) before the program began and 18.6 cases/1000 soldier-months 5–14 months after the program began (relative risk (after/before)=0.5, $p < 0.01$). Thus, the decline in injury rates corresponded in time to the implementation of the program. However, a major potential confounder was the switch in how medical surveillance data was recorded. The hospital switched from the use of the Ambulatory Data System (ADS) to another system called KG-ADS (intended as an automated upgrade to ADS). Providers considered the KG-ADS cumbersome and time-consuming, possibly resulting in provider impatience and miscoding. A number of other potential temporal confounders (paving of the shoulders of the roads at Fort Drum, the Pool Therapy Program, physical therapist turnover, recorder bias, a deployment to Bosnia, and seasonal variations) were considered and discounted. It was considered imperative that the program be tested in a randomized prospective cohort study.

e. <u>Injury Incidence and Injury Risk Factors in Basic Training.</u>

(1) Cumulative injury incidence (proportion of trainees with one or more injuries during training) and injury rates (injured trainees per month) has been examined in the basic training units of the Army, Navy, Marine Corps, and Air Force (8, 70, 74-86). These data are shown in Table 1. US Army BCT was extended from 8 to 9 weeks in October 1998 and thus studies performed before and after this time are separated in Table 1 to reflect the increased time at risk in the latter investigations. Two investigations are included of US Army infantry basic training, which is 12 weeks long.

(2) With regard to data collection, most investigations used medical records screening (78, 79, 85, 87-90), but other studies used medical surveillance systems (8, 86, 91) or questionnaires (80). With regard to injury definitions, most studies have looked at cases where trainees reported to a medical care provider for any type of physical damage to the body (8, 79, 81, 85, 86, 89, 90), but other studies have included only musculoskeletal injuries (78) or lower extremity overuse injuries (6, 78, 88). One study used self-reporting and included any injury regardless of whether or not the trainees sought medical care (80).

Table 1. Cumulative Incidence of Injury and Injury Incidence Rates during Army, Navy, Marine and Air Force Basic Training

Service	Length of Training (weeks)	Study (Reference Number)	Year Data Collected	Recruits (n)		Cumulative Injury Incidence (%)		Injury Incidence Rate (%/month)	
				Men	Women	Men	Women	Men	Women
Army	8 weeks	92[a]	1978	347	770	26.2	62.0	13.1	31.0
		79	1980	1,840	644	20.7	41.2	10.4	20.6
		78	1984	124	186	27.4	50.5	13.7	25.3
		87	1988	509	352	27.0	57.0	13.5	28.5
		85	1994	ND[b]	165	ND[b]	66.7	ND[b]	33.3
		88	1996	159	84	41.5	65.5	20.8	32.8
		81	1998	604	305	30.8	58.0	15.4	29.0
	9 weeks	89	1998	655	498	29.98	65.3	13.3	29.0
		90[c]	2000	682/441	579/554	13.5/16.9	36.1/46.8	6.0/7.5	16.0/20.8
		91[cd]	2003	442/569	295/377	19.5/27.9	41.0/47.7	8.7/12.4	18.2/21.2
		86	2007	2,147	915	36.9	64.7	16.4	28.8
	12 weeks (Infantry)	77	1988	303	ND[b]	45.9	ND[b]	15.3	ND[b]
		[e]	1996	768	ND[b]	48.0	ND[b]	16.0	ND[b]
Marine Corps	12 weeks	93	1993	1,143	ND[b]	33.1	ND[b]	11.0	ND[b]
		94	1995–96	ND[b]	2,766	ND[b]	44.0	ND[b]	14.7
		84	1993–94	176	241	25.6	44.0	8.5	14.7
		95	1993	434	366	22.8	53.0	8.3	16.3
		6	1999	ND[b]	824	ND[b]	48.4	ND[b]	16.1
Navy	9 weeks	94	1996	ND[b]	8,865	ND[b]	37.2	ND[b]	12.4
Air Force	6 weeks	8	1994–95	8,660	5,250	16.8	37.8	11.2	25.2

a. Injury data from self-report questionnaire
b. ND=No data collected on other gender
c. Cohort study with two groups
d. Injury data from surveillance system
e. Previously unpublished data (1998)

(3) In addition to injury rates and incidence, injury risk factors have been identified in some of the military Services. Like comparison of injury rates, relative risks across Services cannot be quantitatively compared because of different injury collection methods and different injury definitions. Further, some risk factors identified in one Service have not been investigated in other Services. Risk factors that have been identified are as follows. In Army and Marine Corps training, risk factors included female gender (8, 75-84), low aerobic fitness (6, 7, 75, 76, 78, 81, 85, 93, 95, 96), cigarette smoking prior to BCT (77, 81, 95-97), and low physical activity prior to basic training (6, 7, 70, 76-78, 81, 96). In Army and Navy trainees, longer running mileage during basic training is an injury risk factor (98, 99). Risk factors examined and identified only in Army BCT include low muscular endurance (77, 81) and training in the

summer compared with the fall (100). In male Marines only, older running shoes were associated with a higher risk of stress fractures (70). Among female Marines, menstrual irregularities have been associated with higher injury risk (6). Multivariate analyses in Army basic training have shown that cigarette smoking prior to BCT, low levels of aerobic fitness, and low levels of physical activity prior to BCT were independent injury risk factors (77, 81, 101).

5. METHODS.

a. Subjects and Study Design.

(1) The subjects of this study were men and women involved in BMT at Lackland Air Force Base, Texas. On entry to BMT, potential volunteers were briefed on the purposes and risks of the study and those wishing to participate in the investigation signed an informed consent statement. The informed consent statement and research protocol were approved the institutional review board of Wilford Hall Medical Center at Lackland Air Force Base, Texas (Appendix C).

(2) This was a randomized prospective cohort study. Volunteers were randomized into either an experimental (E) or control (C) group in sequential order, generally based on order of arrival for testing. The E group subjects were prescribed a running shoe based on the shape of the plantar surface of their feet. The C group subjects received a standard stability running shoe (New Balance 498) regardless of the shape of their plantar surface. All enrolled volunteers were followed until BMT graduation or separation from their original BMT unit.

b. Initial Testing Procedures.

(1) All initial testing was performed in the clothing issue room at Lackland AFB between April and June 2007. Immediately after the informed consent was obtained, volunteers were administered a questionnaire that asked about tobacco use, physical activity, injury history, and (for women) menstrual history. This questionnaire is in Appendix D.

(2) To determine the shape of the plantar surface of the foot (plantar surface evaluation), the barefoot volunteer mounted the acrylic platform of the light box device shown in Figure 1. The device contained a mirror that reflected the underside of the trainee's foot. This provided a view of the footprint, showing the amount of the foot that was in contact with the acrylic surface. The subjects were instructed to stand with equal weight on each foot and feet comfortably apart. The area encompassed by the footprint was examined by two testers who stood side by side. The testers made independent determinations of the plantar surface as either high arched, normal arched or low arched, based on templates (1): more area in the middle third of the plantar surface indicated a low plantar shape and less area a high plantar shape. If the assessments of the two raters differed, they discussed the assessment and reached a consensus.

Figure 1a.High-Arched Feet

Figure 1b. Normal Arched Feet

Figure 1. Plantar Foot Shape Device

(3) After the plantar foot shape determinations, subjects' foot lengths and foot arch heights were measured with the device shown in Figures 2 and 3. Total foot length and medial metatarsal phalangeal joint (MPJ) length were determined using a measuring ruler built into the device. Total foot length was measured as the distance from the most distal aspect of the first toe to the most posterior part of the heel. MPJ length was measured as the distance from the first MPJ to the most posterior part of the heel. Foot arch height was measured with a digital caliper (Figure 3) as the distance from standing surface to the inferior medial border of the navicular tuberosity. The three measures were obtained on both the right and left foot while the subject was standing with weight equally distributed on both feet.

Figure 2. Device Used to Measure Foot Arch Height

Figure 3. Foot Length and Arch Height Measurements Being Taken on a Subject

c. Running Shoe Prescription. Subjects in the C group received a New Balance 498 shoe regardless of plantar surface shape. Trainees in the E group received a shoe based on the determined shape of the plantar surface of their foot. If a subject in the E group was classified as having a low plantar shape, a New Balance 587 (motion control shoe) was prescribed. If a subject in the E group was classified as having a high plantar shape, a New Balance 755 (cushion shoe) was prescribed. If a subject in the E group was classified as having a normal plantar shape, a New Balance 498 (stability shoe) was prescribed. For subjects in the E group, if the plantar shape determination was different for a subject's right foot and left foot, the raters determined the degree of difference and prescribed a shoe appropriate for the "average." For example, a subject with a moderately high left foot arch and a normal right foot arch would be assigned a stability shoe since the left foot arch was not extremely high. Soldiers received their shoes in the clothing issue area just after the foot evaluations.

d. Attrition from Training. Some subjects did not complete the entire 6-week BMT cycle but their data were included for the time they remained in training, as described below. Reasons for attrition included discharge from the Air Force or reassignment to a new unit (recycle). Discharges and recycles were obtained from a local data system maintained at Lackland AFB.

e. Physical Fitness Test Scores. Within 2 to 5 days of arrival in their training units, recruits took the physical fitness test. The test was repeated in the fifth week of training. The test consisted of three events: a 1-minute maximal effort push-up event, a 1-minute maximal effort abdominal crunch event, and a 1.5-mile run for time, administered in that order. The three fitness test events were administered by military training instructors using standardized procedures. For the push-up, the subject lowered his or her body in a generally straight line to a point where the upper arms were parallel to the ground, and then returned to the starting point with elbows fully extended. For the crunch, the subject's knees were bent at a 90° angle and arms were placed across the chest with the hands resting on the shoulders or upper chest. A second person was allowed to hold the subject's feet to keep the heels firmly on the ground. The subject raised his or her upper body to a vertical position so that elbows touched the knees or thighs and then returned to the starting position such that the shoulder blades touched the ground before beginning a new repetition. Scores were the number of push-ups or crunches successfully completed within a 1-minute time period. The performance measure for the run was the time taken to complete the 1.5-mile distance. Time between events was no less than 10 minutes.

f. Physical Characteristics. Height and weight were obtained in the clothing issue facility during the initial testing. A three-dimensional body scanner (Human Solutions, Kaisenslautern Germany) incorporated a force platform to measure weight and the laser on the device measured height. Abdominal circumference was measured during the physical fitness tests with an anthropometric tape. The tape was placed parallel to the floor at the level of the iliac crest and the measurement was made at the end of a normal expiration.

g. Demographics. The Army Medical Surveillance Activity (now the Armed Forces Health Surveillance Center) provided demographic data for study subjects from the Defense Medical Surveillance System (DMSS). The DMSS regularly and systematically incorporates into their systems demographic data from the Defense Manpower Data Center (DMDC) and the Military Entrance Process Command (MEPS). Information obtained from the DMSS for study subjects included date of birth, component (active, reserve, National Guard), educational level, marital status, and race.

h. Injury Outcome Measures.

(1) Besides demographic data, the DMSS (now the Armed Forces Health Surveillance Center) regularly incorporates data on ambulatory (outpatient) encounters that occur within military treatment facilities (MTFs), as well as those that occur outside the MTFs but are paid for by the DOD. The DMSS provided visit dates and ICD-9 codes for all outpatient medical visits within the BMT timeframe for each subject. The first four diagnoses for each visit were considered, although a single visit usually included only one diagnosis. Five injury indices were calculated: the Installation Injury Index (III), the Modified Installation Injury Index (MIII), the Training Injury Index (TII), the Comprehensive Injury Index (CII), and the Overuse Injury Index (OII). All indices include specific ICD-9 codes, as described previously (83).

(2) The III and TII were developed by personnel at the DMSS. The III has been used to compare overall injury rates (acute and overuse) among military posts and is reported on a monthly basis at the Armed Forces Healthy Surveillance Center website (http://afhsc.army.mil). The TII is limited to lower extremity overuse injuries and has been used to compare injury rates

among basic training posts. The TII is reported on a monthly basis to the Army Training and Doctrine Command surgeon.

(3) The MIII, CII, and OII were developed by personnel in the Injury Prevention Program at the CHPPM. The MIII captures a greater number of injuries than the III, including more overuse type injuries. The CII captures all ICD-9 codes related to injuries. The OII captures the subset of musculoskeletal injuries presumably resulting from cumulative microtrauma (overuse-type injuries) such as stress fractures, stress reactions, tendonitis, bursitis, fasciitis, arthralgia, neuropathy, radiculopathy, shin splints, synovitis, strains, and musculoskeletal pain (not otherwise specified).

i. <u>Data Analysis.</u>

(1) Age was calculated from the date of birth in the DMDC data to the date of the informed consent briefing. Body mass index (BMI) was calculated as weight/height^2 (102). Foot arch indices for each foot were calculated using total foot length, MPJ length, and arch height. The arch index was defined as the arch height divided by the total foot length. The bony arch index was defined as the arch height divided by the MPJ length. The arch index and bony arch index were developed because it might be assumed that an individual with a greater foot length might have a higher foot arch.

(2) The E and C groups were compared on questionnaire variables, attrition, age, physical characteristics, physical fitness, demographic characteristics, foot measurements and foot indices. For discrete, nominal, and ordinal variables comparisons were made using the chi-square statistic; for continuous measures, E and C group comparisons were performed using an independent sample t-test. Between-rater reliability of plantar foot shape determination was made with the kappa coefficient. A two-way analysis of variance (ANOVA) was used to compare the groups on physical characteristics and fitness measures before and after BMT (groups × test period ANOVA with repeated measures on the test period).

(3) For all injury indices, person-time injury incidence rates (injured subjects/1000 person-days) were calculated as:

$$(\text{Subjects with} \geq 1 \text{ injury}) \div (\text{total subject time in BMT} \times 1000)$$

The total time in BMT was 43 days for subjects who completed BMT and less for those who attrited from training. Comparisons between the E and C groups were made using a chi-square for person-time (103).

(4) Cox regression was used to examine the associations between potential risk factors (including group membership) and time to first CII injury. For each analysis, once a subject had an injury his or her contribution to time in BMT was terminated. Those who attrited from

training had their time censored (i.e., end of time at risk) at the day they left the unit. All potential risk factors were entered into the regression model as categorical variables. Some interval and ordinal variables were combined to increase statistical power. Most continuous variables were converted to four equal-sized groups based on the distribution of the scores. Age was partitioned into 3 groups (17–19, 20–24, ≥ 25 years). Arch height measures and arch indices were separated into groups comprising the highest 20% and lowest 20% of values (leaving 60% in the central distribution). For all Cox regressions, simple contrasts were used, comparing the hazard at a baseline level of a variable (defined with a hazard ratio (HR) of 1.00) to other levels of the same categorical variable. Univariate Cox regressions established the association between time to first injury and levels of each potential risk factor in isolation. Multivariate Cox regressions established the effect of multiple risk factors (including group membership) on injury risk. Potential risk factors were included in the multivariate model if they achieved $p< 0.10$ in the univariate analyses (104).

(5) Measures of arch height and the arch indices were compared with plantar surface determinations. Analysis of variance (ANOVA) was used to determine if there were differences in the measured arch heights and arch indices for the three plantar shapes (low, normal, and high). To determine the number of subjects correctly classified, the proportion (%) of subjects in the each of the three plantar shapes was established and compared with the same distributions in the measured arch height and arch indices.

6. RESULTS.

a. <u>Participants and Attrition.</u>

(1) There were 2,167 men and 854 women who volunteered for the study. The first group began BMT on 28 April 2007 and graduated on 10 June 2007. The last group began BMT on 2 June 2007 and graduated on 15 July 2007.

(2) Of the original cohort of volunteers 113 (60 men and 53 women) did not enter BMT for medical or administrative reasons. These subjects were not considered in further analyses since they had no actual time in BMT. There were 206 recycles (128 men, 78 women). The recycle database did not have the day the subject was recycled so the time at risk could not be determined; these subjects were not considered in subsequent analyses. Thus, the final cohort considered for analysis consisted of 1,979 men and 723 women.

(3) Among the men, 8.9% in the E group and 8.2% in the C group attrited from training ($p=0.58$). Among the women, 16.0% of the E group and 11.3% of the C group attrited from training ($p=0.07$). These subjects were considered for analysis until the time they left training.

b. Comparisons of E and C Groups. Not all subjects had complete measurements on all variables. This occurred primarily because the data were not available in the DMSS databases, subjects did not provide a response on the questionnaire, or the training unit did not have the information. Personnel in the clothing issue section imposed time constraints so that some subjects could not complete the entire initial testing battery. Therefore, sample sizes for each variable are shown in all tables below.

(1) **Age, Physical Characteristics, and Fitness Test Scores.** Table 2 compares group differences in age, physical characteristics, and fitness scores for men and women at the start of training. Group differences in these measures were small.

Table 2. Group Comparisons for Age, Physical Characteristics, and Fitness Scores at Start of Training

	Men					Women				
	E		C			E		C		
	n	Mean ±SD	n	Mean ±SD	p-value[a]	n	Mean ±SD	n	Mean ±SD	p-value[a]
Age (yr)	981	21.2±2.3	874	21.2±2.3	0.94	344	21.5±2.9	331	21.3±2.6	0.43
Height (in)	923	69.6±2.7	812	69.6±2.7	0.94	357	64.5±2.7	333	64.8±2.8	0.20
Weight (lb)	924	167±23	814	167±23	0.64	357	138±18	333	139±21	0.81
BMI (kg/m^2)	923	24.3±2.7	812	24.2±2.7	0.64	357	23.4±2.6	333	23.2±2.8	0.43
Abd Cir (in)[b]	921	32.8±3.0	811	32.8±3.1	0.96	350	30.9±3.2	327	30.7±3.4	0.59
Push-Ups (reps)	920	37±13	809	36±13	0.64	355	15±9	332	15±11	0.79
Crunches (reps)	920	37±11	809	37±10	0.71	355	25±10	332	25±11	0.92
1.5-Mile Run (min)	911	12.9±1.8	802	12.9±1.9	0.88	352	16.7±2.7	330	16.6±2.6	0.56

a. Independent sample t-test
b. Abdominal circumference

(a) Table 3 compares group differences as well as changes in physical characteristics and fitness scores from the start to the end of training. Only subjects with complete data on the pre- and post-tests could be considered in the analysis since two-way ANOVA requires complete data. There was no main effect of group or any group × test period interactions on any of the measures. However, pre- to post-BMT changes did show significant main effects: there were significant losses in body weight and BMI and increases in all the fitness measures.

(b) Since there were no group differences in the physical characteristics or fitness measures, the data were combined to calculate mean changes pre- to post-BMT. Means and standard deviations (Mean±SD) are shown in Table 4. Men and women lost weight during training, resulting in a reduction in BMI; men lost more weight than women on both an absolute and relative basis. Improvements on the fitness measures were substantial, but women generally had greater absolute and relative (%) improvements in fitness than the men.

Table 3. Group Comparisons on Physical Characteristics and Fitness Test Scores Pre- and Post-BMT

	E		C		p-values[a]		
	n	Mean ±SD	n	Mean ±SD	Group	Test Period	Group × Test Period
Men							
Pre Weight Post Weight (lb)	787	168±22 161±18	697	166±23 160±18	0.17	<0.01	0.65
Pre BMI Post BMI (kg/m^2)	787	24.4±2.7 23.4±2.0	697	24.2±2.7 23.2±2.0	0.12	<0.01	0.69
Pre Push-Up Post Push-Ups (reps)	814	37±13 53±9	717	37±13 54±9	0.60	<0.01	0.35
Pre Crunches Post Crunches (reps)	814	37±11 56±7	717	37±10 56±7	0.44	<0.01	0.14
Pre 1.5-Mile Run Post 1.5-Mile Run (min)	789	12.7±1.7 11.5±1.3	696	12.7±1.8 11.5±1.9	0.47	<0.01	0.78
Women							
Pre Weight Post Weight (lb)	295	138±17 134±15	290	138±20 135±17	0.68	<0.01	0.45
Pre BMI Post BMI (kg/m^2)	295	23.3±2.6 22.7±1.9	290	23.3±2.6 22.7±1.9	0.51	<0.01	0.35
Pre Push-Up Post Push-Ups (reps)	291	16±9 33±7	283	16±11 33±9	0.68	<0.01	0.68
Pre Crunches Post Crunches (reps)	291	26±10 52±6	284	26±11 51±9	0.74	<0.01	0.36
Pre 1.5-Mile Run Post 1.5-Mile Run (min)	295	16.3±2.3 14.1±1.7	288	16.4±2.5 14.1±1.9	0.86	<0.01	0.90

a. Two-way repeated measures analysis of variance

Table 4. Changes in Physical Characteristics and Fitness Scores with Both Groups Combined

	Men				Women			
	Pre Mean ±SD	Post Mean ±SD	Δ	Δ (%)	Pre Mean ±SD	Post Mean ±SD	Δ	Δ (%)
Weight (lb)	167±23	160±18	7	4.1	138±19	134±16	4	2.6
BMI (kg/m^2)	24.3±2.7	23.3±2.0	1.0	4.1	23.2±2.7	22.6±1.9	0.6	2.6
Push-Ups (reps)	37±13	54±9	17	45.1	16±10	33±8	17	110.8
Crunches (reps)	38±10	56±7	18	49.3	26±10	51±7	25	97.3
1.5-Mile Run (min)	12.7±1.7	11.5±1.6	1.2	9.4	16.4±2.4	14.1±1.8	2.3	14.0

(2) **Demographic Characteristics.** Table 5 shows group comparisons on the demographic variables. The distribution of subjects was similar within the two groups for component, educational level, and marital status for both men and women. The distribution for race was also similar between the two groups of women; however, the E men had a larger proportion of Blacks and smaller proportions of Whites, Asians, and "others" than did the C men.

Table 5. Group Comparisons on Demographic Characteristics

Variable	Level of Variable	Men			Women		
		E(%) n=978	C(%) n=872	p-value[a]	E(%) n=342	C(%) n=331	p-value[a]
Component	Active Air Force	80.8	82.0	0.63	76.3	77.3	0.70
	National Guard	14.8	13.3		14.0	14.8	
	Air Force Reserve	4.4	4.7		9.6	7.9	
Educational Level	< High School Graduate	0.7	0.7	0.32	0.9	1.2	0.93
	High School Graduate	91.6	93.8		90.9	91.5	
	Some College or Graduate	5.0	3.7		6.7	5.7	
	Unknown	2.7	1.8		1.5	1.5	
Race	Asian/Pacific Island	4.2	5.2	0.02	5.8	5.7	0.99
	Black	16.8	11.8		19.6	19.6	
	White	76.4	79.8		69.9	70.4	
	Other	2.4	3.1		4.7	4.2	
	Unknown	0.3	0.1		0.0	0.0	
Marital Status	Single	87.2	89.1	0.34	80.7	83.4	0.32
	Married	12.6	10.6		17.5	16.0	
	Other	0.2	0.3		1.8	0.6	

a. Chi-square statistic

(3) **Questionnaire Data.**

(a) Table 6 compares the groups on the ordinal and nominal questionnaire variables. For most questions, the distribution of E and C subjects across the response categories was similar, although there were a few exceptions. C men had slightly higher frequency of pre-BMT running or jogging than E men; C women also tended to have a slightly higher frequency of running or jogging than E women (Question 15). Slightly fewer E men returned to full activity after a lower limb injury compared with C men (Question 21).

(b) Table 7 examines group differences in the continuous questionnaire variables. Here again, differences between groups were small. E group women tended to have had fewer menstrual periods in the last year and more recent pregnancies compared with C women.

Table 6. Group Comparisons on Ordinal/Nominal Questionnaire Variables

Question	Sample Sizes	Response Category	Men E(%)	Men C(%)	Men p-value[a]	Women E(%)	Women C(%)	Women p-value[a]
Q7. Shoe Type	Men E=747 Men C=681 Women E=265 Women C=249	Boots Dress Running Heels ≤ 1 inch[b] Heels ≥ 1 inch[b] Sandals Other Unsure	10.6 4.0 67.9 --- --- 4.8 9.4 3.3	12.8 3.7 67.0 --- --- 4.6 9.0 3.1	0.87	3.8 3.8 43.4 3.4 9.8 26.4 7.2 2.3	6.8 2.4 47.0 2.0 6.4 26.9 7.2 1.2	0.43
Q8. Smoked 100 Cigarettes in Lifetime	Men E=735 Men C=671 Women E=265 Women C=250	No Yes	68.2 31.8	68.6 31.4	0.88	75.5 24.5	69.6 30.4	0.14
Q13. Self Rating of Physical Activity	Men E=739 Men C=678 Women E=265 Women C=246	Much less than average Somewhat less than average About the same Somewhat more active Much more active	4.9 16.9 36.4 29.4 12.4	5.0 18.3 32.2 33.8 10.8	0.26	7.5 27.5 34.7 22.6 7.5	8.5 24.0 35.4 25.6 6.5	0.83
Q14. Frequency of Exercise or Sports Last 2 Months	Men E=735 Men C=679 Women E=265 Women C=244	Never < 1 time/week 1 time/week 2 times/week 3 times/week 4 times/week 5 times/week 6 times/week ≥ 7 times/week	1.2 5.8 8.8 17.2 25.1 16.8 13.3 5.3 6.4	1.5 5.9 8.2 17.7 22.8 14.4 15.2 6.0 8.2	0.72	5.3 8.7 6.8 20.4 26.8 13.2 10.6 4.2 4.2	2.5 6.6 13.1 18.4 25.4 12.7 8.6 9.0 3.7	0.18
Q15. Frequency of Running or Jogging Last 2 Months	Men E=739 Men C=678 Women E=265 Women C=246	Never < 1 time/week 1 time/week 2 times/week 3 times/week 4 times/week 5 times/week 6 times/week ≥ 7 times/week	3.9 12.3 16.8 20.3 23.1 10.7 6.6 3.4 2.8	4.4 11.2 11.5 24.6 22.3 11.7 9.1 2.2 2.9	0.05	6.4 18.1 9.4 18.9 25.3 13.2 5.7 1.1 1.9	3.7 13.0 15.9 22.8 24.4 9.8 6.5 2.8 1.2	0.11
Q16. Length of Time Ran or Jogged Prior to BMT	Men E=736 Men C=678 Women E=265 Women C=246	Did not run or jog ≤ 1 month 2 months 3 months 4–6 months 7–11 months ≥ 12 months	8.3 31.4 24.0 15.1 11.0 2.7 7.5	8.0 29.2 23.0 15.5 11.8 2.8 9.7	0.79	12.1 30.6 20.4 15.8 9.1 3.4 8.7	6.9 33.3 27.2 15.4 8.1 2.8 6.1	0.25

Table 6. Group Comparisons on Ordinal/Nominal Questionnaire Variables (continued)

Question	Sample Sizes	Response Category	Men E(%)	Men C(%)	Men p-value[a]	Women E(%)	Women C(%)	Women p-value[a]
Q17. Frequency of Exercise with Weights Prior to BMT	Men E=738 Men C=675 Women E=263 Women C=250	Never < 1 time/week 1 time/week 2 times/week 3 times/week 4 times/week 5 times/week 6 times/week ≥ 7 times/week	22.5 16.3 10.4 16.9 16.3 7.9 6.1 2.4 1.2	21.3 16.0 11.9 15.3 14.2 9.9 7.6 2.4 1.5	0.71	35.0 18.6 9.5 14.4 14.8 3.8 3.8 0.0 0.0	34.0 16.0 10.4 14.8 12.4 5.6 4.0 1.2 1.6	0.30
Q18. Consistency of Performing Weight Training ≥ 2 Times/Week	Men E=736 Men C=677 Women E=264 Women C=250	No training ≥ 2 times/week ≤ 1 month 2 months 3 months 4–6 months 7–11 months ≥ 12 months	39.1 15.9 12.8 10.5 8.4 2.9 10.5	38.8 11.8 12.1 11.2 9.7 3.5 12.7	0.30	53.0 15.9 8.0 6..1 7.2 1.9 8.0	50.4 17.2 12.0 6.0 6.8 3.2 4.4	0.43
Q19. Had a Lower Limb Injury	Men E=735 Men C=678 Women E=264 Women C=250	No Yes	79.9 20.1	79.8 20.2	0.97	79.2 20.8	78.4 21.6	0.83
Q20. Did Lower Limb Injury Prevent You from Doing Normal Physical Activity	Men E=735 Men C=678 Women E=264 Women C=250	No injury No Yes	79.9 6.5 13.6	79.8 4.9 15.3	0.30	79.2 4.9 15.9	78.4 6.4 15.2	0.76
Q21. Returned to Normal Physical Activity Since Injury	Men E=735 Men C=678 Women E=264 Women C=250	No injury Yes No	79.9 18.6 1.5	79.8 19.9 0.3	0.05	79.2 19.7 1.1	78.4 18.4 3.2	0.26
Q24. Gone ≥ 6 Months without Menstrual Cycle	Women E=258 Women C=245	No Yes	b			90.3 9.7	91.4 8.6	0.66
Q25. Used Birth Control in Past 12 Months	Women E=254 Women C=244	No Yes				50.0 50.0	56.6 43.4	0.14

a. Chi-square statistic
b. Not considered in the analysis for men

Table 7. Group Comparisons on Continuous Questionnaire Variables

Question	Men					Women				
	E		C			E		C		
	n	Mean±SD	n	Mean±SD	p-value [a]	n	Mean±SD	n	Mean±SD	p-value [a]
Q9. Age Started Smoking (years) [b]	350	16±3	317	16±2	0.11	103	16±3	101	16±2	0.25
Q10. Days Smoked Cigarettes in Last 30 Days [b]	207	17±10	174	19±10	0.29	57	19±10	58	20±9	0.71
Q11. Cigarettes per Day Over Last 30 Days [b]	211	7±6	173	8±8	0.17	56	8±7	55	7±6	0.57
Q12. Quit Smoking (months) [c]	116	13±20	98	14±19	0.48	35	12±20	35	18±23	0.26
Q22. Age at Menarche (years)						256	13±2	246	13±2	0.36
Q23 Menstrual Cycles (n/year)						265	10±4	250	11±3	0.05
Q26. Time Since Last Pregnancy (months)						32	21±21	36	34±31	0.05

a. Independent sample t-test
b. Only subjects who were smokers included
c. Only subjects who said they had quit smoking were included

(4) **Foot Measurements and Arch Indices.**

(a) The kappa coefficient between the two raters on the plantar surface evaluations was 0.98 for the right foot and 0.98 for the left foot. Table 8 shows the distribution of subjects by plantar shape. For both men and women, the C group had a lower proportion of low and high plantar shapes and a greater proportion of normal plantar shapes compared with the E group.

Table 8. Distribution of Subjects by Plantar Shape

Foot	Plantar Shape	Men					Women				
		E		C			E		C		
		n	%	n	%	p-value [a]	n	%	N	%	p-value [a]
Right Foot	Low	134	12.9	79	8.7	<0.01	38	10.8	23	6.7	0.03
	Normal	726	69.7	714	78.3		273	72.8	280	81.2	
	High	181	17.4	119	13.0		64	17.1	42	12.2	
Left Foot	Low	148	14.2	88	9.6	<0.01	44	11.7	27	7.8	0.09
	Normal	703	67.5	696	76.3		256	68.3	259	75.1	
	High	190	18.3	128	14.0		75	20.0	59	17.1	

a. Chi-square statistic

(b) Table 9 compares group differences in the foot measurements and arch indices. All measures are similar for the two groups both among the men and among the women.

Table 9. Group Comparisons on the Foot Measures and Arch Indices

Foot Measures	Men					Women				
	E		C		p-value[a]	E		C		p-value[a]
	n	Mean ± SD	n	Mean ± SD		n	Mean ± SD	n	Mean ± SD	
Left Foot Total Length (cm)	958	26.8±1.3	825	26.8±1.4	0.66	304	24.3±1.2	281	24.3±1.3	0.61
Right Foot Total Length (cm)	958	26.8±13	825	26.7±1.3	0.41	304	24.2±1.2	281	24.2±1.3	0.44
Left Foot MPJ Length (cm)	958	19.9±1.1	825	19.8±1.1	0.43	304	18.1±1.3	281	18.1±1.2	0.72
Right Foot MPJ Length (cm)	958	19.9±1.1	824	19.8±1.1	0.42	304	18.0±1.1	281	18.0±1.0	0.90
Left Foot Arch Height (mm)	957	34.5±7.7	825	34.8±7.5	0.52	304	32.6±7.10	281	32.5±6.7	0.89
Right Foot Arch Height (mm)	957	35.4±7.8	825	35.6±7.7	0.57	304	32.9±7.1	281	33.0±6.6	0.84
Left Arch Index	957	0.1292±0.0331	825	0.1301±0.0292	0.52	304	0.1347±0.0305	281	0.1342±0.0296	0.85
Right Arch Index	957	0.1325±0.0308	825	0.1335±0.0298	0.55	304	0.1365±0.0307	281	0.1367±0.0294	0.93
Left Bony Arch Index	957	0.1747±0.0416	825	0.1761±0.0402	0.48	304	0.1807±0.0402	281	0.1810±0.0408	0.94
Right Bony Arch Index	957	0.1788±0.0420	824	0.1799±0.0406	0.56	304	0.1839±0.0409	281	0.1847±0.0400	0.81

a. Independent sample t-test

c. **Injury Rates and Injury Risk Factors.** The AMSA (now the Armed Forces Health Surveillance Center) returned data on over 99% of those requested. The numbers of subjects requested and returned are displayed in Table 10.

Table 10. Medical Information Requested and Returned from the Army Medical Surveillance Activity (now the Armed Forces Health Surveillance Center)

Men			Women		
Requested	Returned		Requested	Returned	
n	n	%	n	n	%
1979	1955	99.0	723	721	99.7

(1) **Injury Main Analyses.**

(a) Table 11 shows the person-time injury incidence rates for the various injury indices and compares the rates in the E and C groups. For both men and women, group differences in injury rates are slightly higher in E group.

Table 11. Comparison of Injury Incidence Rates between the E and C Groups

Index	Men				Women			
	Injury Incidence Rate (injuries/ 1000 person-days)		Rate Ratio-E/C (95% Confidence Interval)	p-value[a]	Injury Incidence Rate (injuries/ 1000 person-days)		Rate Ratio-E/C (95% Confidence Interval)	p-value[a]
	E	C			E	C		
Installation Injury Index	5.54	4.99	1.11 (0.92–1.35)	0.29	10.14	8.27	1.22 (0.96–1.56)	0.11
Modified Installation Injury Index	5.91	5.39	1.10 (0.92–1.32)	0.33	10.55	8.93	1.18 (0.93–1.49)	0.17
Overuse Injury Index	5.86	5.25	1.12 (0.93–1.35)	0.25	10.55	8.50	1.24 (0.98–1.58)	0.08
Training-Related Injury Index	4.62	3.94	1.17 (0.95–1.45)	0.14	8.41	6.68	1.26 (0.96–1.65)	0.09
Comprehensive Injury Index	7.04	6.43	1.09 (0.92–1.30)	0.30	12.96	10.89	1.19 (0.96–1.47)	0.11

a. Chi-square statistic for person-time (103)

(b) Table 12 shows the univariate Cox regression examining the association of time to first injury with group, age, physical characteristics, and fitness test scores. Among the men, injury risk was about the same for the E and C groups. Higher injury risk was associated with lower performance on push-ups, crunches, or the 1.5-mile run. Men in the middle quartile of BMI or abdominal circumference tended to have lower risk than men with lower BMI or abdominal circumference. Among the women, those in the E group tended to be at higher injury risk than those in the C group. Higher injury risk was also associated with higher BMI, greater abdominal circumference and slower run time on the initial fitness test.

Table 12. Injury Hazard Ratios by Group, Age, Physical Characteristics, and Fitness Test Scores (Univariate Cox Regression)

Variable	Men				Women			
	Level of Variable	n	Hazard Ratio (95%CI)	p-value	Level of Variable	n	Hazard Ratio (95%CI)	p-value
Group	E	1042	1.09 (0.92–1.29)	0.31	E	373	1.23 (1.00–1.53)	0.06
	C	913	1.00	---	C	345	1.00	---
Age	18–19 years	446	1.00	---	18–19 years	154	1.00	---
	20–24 years	1271	1.11 (0.90–1.38)	0.32	20–24 years	442	1.12 (0.85–1.47)	0.42
	≥ 25 years	160	1.29 (0.94–1.81)	0.12	≥ 25 years	80	1.09 (0.73–1.62)	0.67
Height	60.0–67.0 inches	376	0.87 (0.66–1.16)	0.34	57.0–62.5 inches	160	1.04 (0.76–1.44)	0.80
	67.5–69.5 inches	477	0.99 (0.77–1.28)	0.94	63.0–64.5 inches	165	1.04 (0.75–1.43)	0.82
	70.0–71.5 inches	486	1.04 (0.80–1.34)	0.78	65.0–66.5 inches	195	1.25 (0.93–1.69)	0.14
	72.0–81.0 inches	396	1.00	---	67.0–73.0 inches	167	1.00	---
Weight	96–151 pounds	448	1.00	---	90–124 pounds	174	1.00	---
	152–168 pounds	440	0.94 (0.73–1.21)	0.61	125–137 pounds	177	1.01 (0.74–1.37)	0.96
	169–183 pounds	432	0.83 (0.64–1.08)	0.17	138–152 pounds	167	1.00 (0.73–1.36)	0.99
	184–254 pounds	418	1.02 (0.79–1.31)	0.89	153–202 pounds	167	1.21 (0.89–1.65)	0.22
Body Mass Index	14.72–22.28 kg/m^2	432	1.49 (1.09–2.04)	0.01	16.47–21.29 kg/m^2	172	1.04 (0.76–1.43)	0.79
	22.29–24.63 kg/m^2	432	1.00	---	21.30–23.24 kg/m^2	170	1.00	---
	25.64–26.39 kg/m^2	432	0.97 (0.69–1.37)	0.88	23.25–25.67 kg/m^2	172	1.01 (0.73–1.38)	0.97
	26.40–35.44 kg/m^2	430	1.19 (0.86–1.66)	0.30	25.68–30.24 kg/m^2	172	1.35 (1.00–1.83)	0.05
Abdominal Circumference	22.0–30.5 inches	433	1.00	---	23.0–28.2 inches	168	1.00	---
	30.6–32.9 inches	452	1.02 (0.79–1.30)	0.90	28.3–30.6 inches	175	1.03 (0.75–1.42)	0.86
	33.0–35.1 inches	431	0.77 (0.59–1.01)	0.06	30.7–32.9 inches	163	1.17 (0.85–1.60)	0.34
	35.2–41.5 inches	416	1.01 (0.78–1.30)	0.95	33.0–45.2 inches	168	1.30 (0.95–1.77)	0.10
Push-Ups	0–28 repetitions	455	1.49 (1.14–1.93)	<0.01	0–7 repetitions	175	1.26 (0.92–1.71)	0.15
	29–36 repetitions	449	1.05 (0.80–1.39)	0.72	8–14 repetitions	175	0.92 (0.67–1.26)	0.60
	37–45 repetitions	440	1.04 (0.78–1.37)	0.81	15–21 repetitions	183	0.88 (0.64–1.21)	0.45
	46–94 repetitions	385	1.00	---	22–101 repetitions	151	1.00	---
Crunches	0–30 repetitions	459	1.52 (1.18–1.97)	<0.01	0–19 repetitions	180	1.14 (0.84–1.54)	0.41
	31–36 repetitions	417	1.17 (0.89–1.55)	0.25	20–26 repetitions	172	0.88 (0.64–1.21)	0.43
	37–44 repetitions	432	1.13 (0.86–1.48)	0.40	27–32 repetitions	165	1.05 (0.77–1.43)	0.77
	45–75 repetitions	421	1.00	---	33–62 repetitions	167	1.00	---
1.5-Mile Run	8.33–11.53 minutes	432	1.00	---	9.67–14.92 minutes	173	1.00	---
	11.54–12.63 minutes	432	0.95 (0.72–1.26)	0.73	14.93–16.50 minutes	174	0.98 (0.70–1.35)	0.88
	12.64–13.97 minutes	422	1.34 (1.03–1.74)	0.03	16.51–18.23 minutes	164	1.28 (0.93–1.75)	0.13
	13.98–20.53 minutes	427	1.47 (1.13–1.90)	<0.01	18.24–31.40 minutes	169	1.62 (1.19–2.21)	<0.01

(c) Table 13 shows the univariate Cox regression examining the association between time to first injury and the demographic characteristics. Men were at higher injury risk if they were active duty, of Black race or of "other" marital status (primarily divorced or separated). Among women, higher injury risk was associated with lower educational level, White race (compared with Asian descent), "other" race (compared with Whites), and being married.

Table 13. Injury Hazard Ratios for Demographic Characteristics (Univariate Cox Regression)

Variable	Men				Women			
	Level of Variable	n	Hazard Ratio (95%CI)	p-value	Level of Variable	n	Hazard Ratio (95%CI)	p-value
Component	Active Air Force	1526	1.00	---	Active Air Force	518	1.00	---
	National Guard	84	0.79 (0.50–1.24)	0.30	National Guard	59	1.11 (0.76–1.62)	0.59
	Air Force Reserve	262	0.77 (0.59–1.01)	0.06	Air Force Reserve	97	1.18 (0.87–1.60)	0.29
Educational Level	<HS Graduate	13	0.25 (0.04–1.77)	0.16	<HS Graduate	7	2.10 (0.94–4.72)	0.07
	HS Graduate	1735	1.00	---	HS Graduate	614	1.00	---
	Some College/Graduate	82	0.89 (0.57–1.39)	0.61	Some College/Graduate	43	0.93 (0.60–1.48)	0.79
	Unknown	42	0.77 (0.40–1.49)	0.43	Unknown	10	0.83 (0.60–1.48)	0.70
Race	White	1457	1.00	---	White	472	1.00	---
	Black	272	1.24 (0.98–1.56)	0.07	Black	133	1.20 (0.92–1.58)	0.18
	Asian	88	0.75 (0.47–1.20)	0.23	Asian	39	0.60 (0.33–1.06)	0.08
	Other	51	0.76 (0.42–1.39)	0.38	Other	30	1.67 (1.07–2.67)	0.03
	Unknown	4	1.00 (0.14–7.14)	0.99				
Marital Status	Single, Never Married	1649	1.00	---	Single, Never Married	553	1.00	---
	Married	218	1.07 (0.82–1.39)	0.64	Married	113	1.31 (1.00–1.73)	0.05
	Other	5	3.04 (0.98–9.46)	0.06	Other	8	1.50 (0.62–3.63)	0.37

(d) Table 14 shows the association between time to first injury and the questionnaire variables. Among the men, higher injury risk was associated with smoking 100 cigarettes in a lifetime, beginning smoking at a younger age, smoking on any of the 30 days before BMT, and more cigarettes per day in the 30 days before BMT. Among the women, higher injury risk was associated with beginning smoking at a younger age, smoking in the 30 days before BMT, more cigarettes per day in the 30 days before BMT, less frequent running or jogging before BMT, and fewer months of running or jogging before BMT.

Table 14. Injury Hazard Ratios for Questionnaire Variables (Univariate Cox Regression)

Variable[a]	Response Category	Men			Women		
		n	Hazard Ratio (95%CI)	p-value	n	Hazard Ratio (95%CI)	p-value
Q7. Shoe Type Worn Before BMT	Boots	171	1.00	---	27	1.00	---
	Running	972	0.89 (0.66–1.21)	0.46	232	0.95 (0.53–1.69)	0.86
	Dress	55	1.33 (0.79–2.23)	0.29	16	1.77 (0.81–3.88)	0.15
	Heels ≤ 1 inch[b]	---	---	---	14	0.86 (0.33–2.27)	0.77
	Heels >1 inch[b]	---	---	---	40	0.98 (0.48–1.98)	0.95
	Sandals	68	1.03 (0.61–1.72)	0.93	137	1.08 (0.60–1.96)	0.80
	Other	132	0.94 (0.61–1.45)	0.78	37	1.00 (0.49–2.06)	0.99
	Unsure	46	0.87 (0.46–1.64)	0.67	9	0.89 (0.29–2.72)	0.83
Q8. Smoked 100 Cigarettes in Life	No	969	1.00	---	373	1.00	---
	Yes	453	1.29 (1.05–1.58)	0.02	140	1.21 (0.92–1.60)	0.18
Q9. Age Started Smoking	Never Smoked	773	1.00	---	310	1.00	---
	6–9 years old	8	2.37 (0.87–6.29)	0.09	0	---	---
	10–14 years old	160	1.44 (1.07–1.95)	0.02	56	1.44 (0.98–2.13)	0.07
	15–19 years old	467	1.17 (0.93–1.46)	0.17	139	1.17 (0.87–1.57)	0.29
	≥ 20 years old	40	1.51 (0.89–2.55)	0.13	8	1.33 (0.49–3.58)	0.58

Table 14. Injury Hazard Ratios for Questionnaire Variables (Univariate Cox Regression) (continued)

Variable[a]	Response Category	Men			Women		
		n	Hazard Ratio (95%CI)	p-value	n	Hazard Ratio (95%CI)	p-value
Q10. Smoked Cigarettes in Last 30 Days	No Yes	1064 386	1.00 1.41 (1.14–1.74)	--- <0.01	400 114	1.00 1.30 (0.97–1.74)	--- 0.08
Q11. Cigarettes per Day in Last 30 Days	None 1–9 cigarettes/day ≥10 cigarettes/day	1060 241 149	1.00 1.29 (1.00–1.67) 1.47 (1.09–1.99)	--- 0.05 <0.01	404 64 46	1.00 1.50 (1.05–2.15) 1.49 (0.98–2.27)	--- 0.03 0.09
Q12. Smokers and Quitters	Never Smoker Quit	893 386 171	1.00 1.43 (1.15–1.78) 1.11 (0.82–1.52)	--- <0.01 0.51	341 114 59	1.00 1.29 (0.95–1.74) 0.95 (0.63–1.44)	--- 0.10 0.81
Q13. Self Rating of Physical Activity	Much Less Active Somewhat Less Active About the Same Somewhat More Active Much More Active	70 251 491 453 167	1.11 (0.67–1.85) 0.93 (0.64–1.35) 1.04 (0.75–1.44) 0.80 (0.57–1.13) 1.00	0.69 0.70 0.81 0.21 ---	40 131 178 123 37	1.20 (0.63–2.30) 1.09 (0.64–1.84) 1.22 (0.74–2.03) 0.90 (0.53–1.55) 1.00	0.57 0.76 0.44 0.71 ---
Q14. Frequency of Exercise or Sports Before BMT	≤ 1 time/week 2–4 times/week ≥ 5 times/week	223 818 391	0.85 (0.61–1.18) 1.01 (0.80–1.27) 1.00	0.33 0.93 ---	109 297 101	1.24 (0.83–1.86) 1.24 (0.88–1.75) 1.00	0.30 0.22 ---
Q15. Frequency of Running/Jogging Before BMT	≤ 1 time/week 2–4 times/week ≥ 5 times/week	431 806 196	1.01 (0.72–1.41) 1.14 (0.84–1.55) 1.00	0.96 0.40 ---	168 291 50	1.71 (1.03–2.84) 1.43 (0.87–2.33) 1.00	0.04 0.16 ---
Q16. Length of Time Running/Jogging Before BMT	≤ 1 month 2–6 months ≥ 7 months	547 719 164	1.19 (0.84–1.68) 1.14 (0.81–1.60) 1.00	0.34 0.47 ---	210 244 55	1.57 (0.96–2.56) 1.64 (1.01–2.65) 1.00	0.07 0.05 ---
Q17. Frequency of Exercise with Weights, Last 2 Months	≤ 1 time/week 2–4 times/week ≥ 5 times/week	701 575 153	0.94 (0.67–1.31) 1.09 (0.78–1.53) 1.00	0.71 0.61 ---	316 168 27	0.94 (0.54–1.63) 1.04 (0.59–1.84) 1.00	0.83 0.89 ---
Q18. Consistency of Performing Weight Training ≥ 2 Times/Week	≤ 1 month 2–3 months 4–6 months ≥ 7 months	755 331 129 214	1.08 (0.81–1.45) 1.01 (0.72–1.41) 1.13 (0.74–1.70) 1.00	0.61 0.95 0.58 ---	350 81 36 45	0.99 (0.64–1.56) 1.08 (0.64–1.81) 1.16 (0.63–2.13) 1.00	0.99 0.77 0.63 ---
Q19. Prior Lower Limb Injury	No Yes	1142 287	1.00 1.01 (0.80–1.30)	--- 0.89	403 109	1.00 0.99 (0.72–1.35)	--- 0.93
Q20. Did Lower Limb Injury Prevent Activity	No Yes	81 207	1.00 1.12 (0.68–1.83)	--- 0.67	29 80	1.00 1.24 (0.65–2.38)	--- 0.51
Q21. After Recovery, Returned to 100%	No Yes	13 274	0.53 (0.13–2.15) 1.00	0.37 ---	11 98	0.73 (0.26–2.02) 1.00	0.54 ---
Q22. Age at Menarche	8–10 years 11–14 years 15–26 years		b		29 406 65	1.11 (0.63–1.95) 1.00 1.33 (0.93–1.89)	0.71 --- 0.11
Q23. Menstrual Periods in Last Year	0 1–9 10–12 ≥ 13				23 58 409 23	1.32 (0.74–2.36) 1.07 (0.72–1.58) 1.00 0.85 (0.44–1.66)	0.36 0.74 --- 0.64

Table 14. Injury Hazard Ratios for Questionnaire Variables (Univariate Cox Regression) (continued)

Variable[a]	Response Category	Men			Women		
		n	Hazard Ratio (95%CI)	p-value	n	Hazard Ratio (95%CI)	p-value
Q24. 6 Months without Cycles, in Last Year	No Yes	b			455 46	1.00 1.02 (0.66–1.56)	--- 0.94
Q25. Taken Birth Control Pills, Last 12 Months	No Yes				264 232	1.00 0.97 (0.75–1.25)	--- 0.80
Q26. Time Since Last Pregnancy	Never Pregnant 1–6 months 7–12 months ≥ 12 months				446 9 16 43	1.00 1.42 (0.59–3.45) 1.38 (0.71–2.69) 1.04 (0.66–1.64)	--- 0.44 0.35 0.87

a. "Q" followed by a number indicates the question number (see Appendix D)
b. Not included in the analysis for men

(e) Table 15 shows the association between injury risk and the plantar surface determinations. Men and women with lower plantar surfaces generally had higher injury risk than those with normal plantar surfaces. Men with high left foot plantar surfaces also tended to have higher injury risk than men with normal plantar surfaces on the left foot; however, this was not seen for men on the right foot.

Table 15. Injury Hazard Ratios for Plantar Surface Evaluations (Univariate Cox Regression)

Foot	Plantar Surface Determination	Men			Women		
		n	Hazard Ratio (95%CI)	p-value	n	Hazard Ratio (95%CI)	p-value
Left	Low Normal High	236 1399 318	1.26 (0.98–1.62) 1.00 1.21 (0.97–1.52)	0.07 --- 0.09	70 514 133	1.41 (1.01–1.98) 1.00 1.04 (0.79–1.38)	0.04 --- 0.79
Right	Low Normal High	213 1440 300	1.29 (1.00–1.36) 1.00 1.08 (0.86–1.36)	0.05 --- 0.52	60 552 105	1.32 (0.92–1.89) 1.00 0.92 (0.67–1.26)	0.14 --- 0.62

(f) Table 16 shows the association between the time to the first injury and arch height, arch index, and bony arch index. For each variable, data are grouped in the lowest 20% of values, middle 60% of values, and highest 20% of values. For both men and women, higher injury risk tends to be associated with being in the lower 20% of arch height, arch index, or lower bony arch index, compared with the midrange. There is little association between injury risk and higher arch height, arch index, or bony arch index when compared with the midranges.

Table 16. Injury Hazard Ratios for Arch Height and Arch Indices (Univariate Cox Regression)

Variable	Men				Women			
	Level of Variable (Proportional Distribution Within Variable)	n	Hazard Ratio (95%CI)	p-value	Level of Variable (Proportional Distribution Within Variable)	n	Hazard Ratio (95%CI)	p-value
Arch Height Left	12.8–27.9 mm (low 20%) 28.0–40.8 mm (mid 60%) 40.9–61.3 mm (high 20%)	357 1072 356	1.11 (0.89–1.39) 1.00 0.86 (0.68–1.09)	0.36 --- 0.22	8.8–26.7 mm (low 20%) 26.8–38.0 mm (min 60%) 38.1–53.1 mm (high 20%)	116 349 117	1.61 (1.21–2.13) 1.00 0.97 (0.71–1.34)	<0.01 --- 0.89
Arch Height Right	12.6–28.4 mm (low 20%) 28.5–41.8 mm (mid 60%) 41.9–60.6 mm (high 20%)	357 1071 357	1.43 (1.15–1.78) 1.00 1.07 (0.85–1.35)	<0.01 --- 0.56	15.5–27.4 mm (low 20%) 27.5–38.5 mm (mid 60%) 38.6–57.6 mm (high 20%)	116 349 117	1.41 (1.07–1.89) 1.00 0.91 (0.66–1.26)	0.02 --- 0.58
Arch Index Left	0.0439–0.1030 (low 20%) 0.1031–0.1539 (mid 60%) 0.1540–0.2428 (high 20%)	357 1071 356	1.28 (1.03–1.60) 1.00 0.94 (0.74–1.19)	0.03 --- 0.61	0.0358–0.1104 (low 20%) 0.1105–0.1577 (mid 60%) 0.1578–0.2395 (high 20%)	116 349 117	1.54 (1.17–2.04) 1.00 0.88 (0.64–1.21)	<0.01 --- 0.43
Arch Index Right	0.0568–0.1125 (low 20%) 0.1126–0.1616 (mid 60%) 0.1617–0.2417 (high 20%)	357 1071 356	1.40 (1.13–1.73) 1.00 1.05 (0.83–1.33)	<0.01 --- 0.68	0.0568–0.1125 (low 20%) 0.1126–0.1616 (mid 60%) 0.1617–0.2417 (high 20%)	116 349 117	1.29 (0.97–1.72) 1.00 0.89 (0.63–1.18)	0.08 --- 0.36
Bony Arch Index Left	0.0489–0.1471 (low 20%) 0.1472–0.2132 (mid 60%) 0.2132–0.3024 (high 20%)	357 1071 357	1.29 (1.04–1.61) 1.00 1.02 (0.81–1.29)	<0.01 --- 0.84	0.0489–0.1471 (low 20%) 0.1472–0.2132 (mid 60%) 0.2133–0.3024 (high 20%)	116 349 117	1.55 (1.17–2.05) 1.00 0.88 (0.64–1.22)	<0.01 --- 0.44
Bony Arch Index Right	0.0799–0.1511 (low 20%) 0.1512–0.2180 (mid 60%) 0.2181–0.3213 (high 20%)	357 1071 356	1.38 (1.11–1.71) 1.00 0.98 (0.78–1.25)	<0.01 --- 0.98	0.0799–0.1511 (low 20%) 0.1512–0.2180 (mid 60%) 0.2181–0.3213 (high 20%)	116 349 117	1.47 (1.11–1.95) 1.00 0.86 (0.62–1.19)	<0.01 --- 0.86

(g) Table 17 shows the results of the backward stepping multivariate Cox regression with group membership (E and C groups) forced into the model. Subjects with complete data on all the variables included 1,268 men (65% of the male sample) and 365 women (51% of the female sample). Among the men, injury risk was about the same for the E and C groups. Injury risk was independently associated with slower run times and smoking cigarettes in the 30 days before BMT. Among the women, injury risk was about the same for the E and C groups. Injury risk was independently associated with slower run times, smoking cigarettes in the 30 days before BMT, less time running or jogging prior to BMT, marriage, and lower bony arch index.

Table 17. Injury Hazard Ratios for Study Variables (Multivariate Cox Regression)

Variable	Level of Variable	n	Hazard Ratio (95%CI)	p-value
Men				
Group	E C	658 610	1.11 (0.89–1.38) 1.00	0.35 ---
1.5-Mile Run	8.33–11.53 minutes 11.54–12.63 minutes 12.64–13.97 minutes 13.98–20.53 minutes	330 305 310 323	1.00 0.92 (0.66–1.29) 1.33 (0.97–1.80) 1.42 (1.05–1.93)	--- 0.64 0.07 0.02
Q10. Smoked Cigarettes in Last 30 Days	No Yes	929 339	1.00 1.28 (1.01–1.61)	--- 0.04

Table 17. Injury Hazard Ratios for Study Variables (Multivariate Cox Regression) (continued)

Variable	Level of Variable	n	Hazard Ratio (95%CI)	p-value
Women				
Group	E C	187 178	1.14 (0.85–1.55) 1.00	0.38 ---
1.5–Mile Run	9.67–14.92 minutes 14.93–16.50 minutes 16.51–18.23 minutes 18.24–31.40 minutes	103 98 83 81	1.00 1.16 (0.75–1.80) 1.11 (0.70–1.75) 1.95 (1.24–3.05)	--- 0.51 0.66 <0.01
Q10. Smoked Cigarettes in Last 30 Days	No Yes	297 68	1.00 1.39 (0.95–2.05)	--- 0.10
Q16. Length of Time Running/ Jogging Before BMT	≤ 1 month 2–6 months ≥ 7 months	147 179 39	1.21 (0.62–2.34) 1.74 (0.94–3.22) 1.00	0.58 0.08 ---
Marital Status[b]	Single Married	310 55	1.00 1.53 (1.04–2.27)	--- 0.03
Bony Arch Index, Left	Low (lower 20%) Normal (middle 60%) High (highest 20%)	69 219 77	1.80 (1.25–2.58) 1.00 0.91 (0.61–1.35)	<0.01 --- 0.63

b. None of the “other” marital status women were included in this analysis because only 2 subjects in this category had complete data on other variables

(2) Injury Subgroup Analyses.

(a) Within the E and C groups, injury risk was examined for the three plantar foot shapes. Table 18 shows the univariate Cox regression. Among the C men (all of whom wore the stability shoe), there was little difference in injury risk by plantar shape. Among the E group men, individuals with low plantar shapes who wore the motion control shoe had a higher injury risk than individuals with normal plantar shapes who wore the stability shoe. Men and women with high plantar shapes had injury risk similar to that of their normal plantar–shaped counterparts.

Table 18. Injury Hazard Ratios by Group and Plantar Foot Shape (Univariate Cox Regression)

			Men			Women		
Subjects	**Shoe Type**	**Plantar Foot Shape**	**n**	**Hazard Ratio (95%CI)**	**p-value**	**n**	**Hazard Ratio (95%CI)**	**p-value**
C Subjects Only	Stability Stability Stability	Low Normal High	79 714 119	1.09 (0.70–1.70) 1.00 1.11 (0.77–1.59)	0.69 --- 0.59	23 280 41	1.50 (0.83–2.72) 1.00 0.84 (0.50–1.40)	0.18 --- 0.50
E Subjects Only	Motion Control Stability Cushion	Low Normal High	134 726 181	1.39 (1.02–1.43) 1.00 1.06 (0.76–1.43)	0.04 --- 0.73	37 272 64	1.16 (0.74–1.84) 1.00 0.95 (0.64–1.41)	0.52 --- 0.79

(b) Injury risk for the E and C groups was compared within plantar foot shapes. Table 19 shows the results of the univariate Cox regression. Among those with normal plantar shapes, all of whom wore stability shoes, E women tended to have a higher injury risk than C women. Among those with low plantar shapes, E men who wore motion control shoes (presumably designed for their foot type) tended to have a higher injury risk than C men who wore a stability shoe, although the difference was not statistically significant. Among women with high plantar shapes, E women who wore the cushioned shoe (presumably designed for their foot type) tended to have a higher injury risk than C women who wore a stability shoe, although the difference was not statistically significant.

Table 19. Injury Hazard Ratios Comparing E and C Groups within Each Plantar Foot Shape (Univariate Cox Regression)

Plantar Foot Shape	Group	Shoe	Men			Women		
			n	Hazard Ratio (95% CI)	p-value	n	Hazard Ratio (95% CI)	p-value
Normal	E C	Stability Stability	726 714	1.05 (0.86–1.29) 1.00	0.62 ---	272 280	1.24 (0.97–1.58) 1.00	0.09 ---
Low	E C	Motion Control Stability	134 79	1.33 (0.80–2.21) 1.00	0.27 ---	37 23	0.95 (0.47–1.93) 1.00	0.89 ---
High	E C	Cushion Stability	181 119	1.01 (0.82–1.58) 1.00	0.98 ---	64 41	1.41 (0.78–2.58) 1.00	0.27 ---

(c) A separate analysis was performed comparing injury risk among only those individuals with high or low plantar shapes in the E and C groups. This removes the subjects with normal plantar shapes from the analysis and compares only the extreme plantar shapes. Table 20 shows that injury risk was about the same in the E and C groups (though slightly higher in the E group).

Table 20. Injury Hazard Ratios by Group with Only High/Low-Arched Individuals by Plantar Surface Evaluation (Univariate Cox Regressions)

Group	Men			Women		
	n	Hazard Ratio (95%CI)	p-value	n	Hazard Ratio (95%CI)	p-value
E C	315 198	1.14 (0.82–1.58) 1.00	0.43 ---	101 64	1.23 (0.77–1.94) 1.00	0.40 ---

d. <u>Comparison of Plantar Surface Determination with Arch Height and Arch Indices.</u>

(1) Table 21 shows the plantar surface determinations with means and standard deviations of (Mean±SD) arch heights and arch indices. Progressively higher plantar shapes (i.e., from low to normal to high) had a correspondingly higher mean arch height, arch index, or bony arch index. Differences between all the plantar surface determinations, for all three

measures were significant by the Tukey test (p< 0.01). Differences between the low and normal plantar surfaces were much greater than between the normal and high plantar surfaces.

Table 21. Plantar Surface Determination and Corresponding Arch Height and Arch Indices

Gender, Foot	Plantar Surface Determination	n	Arch Height (mm) (mean ±SD)	p-value[a]	Arch Index (mean ±SD)	p-value[a]	Bony Arch Index (mean ±SD)	p-value[a]
Men, Left	Low	222	26.5±6.0	<0.01	0.0975±0.0232	<0.01	0.1309±0.0313	<0.01
	Normal	1269	35.4±7.0		0.1325±0.0273		0.1792±0.0374	
	High	291	37.6±7.3		0.1417±0.0286		0.1923±0.0399	
Men, Right	Low	200	27.6±5.7	<0.01	0.1018±0.0216	<0.01	0.1357±0.0292	<0.01
	Normal	1308	36.0±7.3		0.1350±0.0284		0.1821±0.0384	
	High	274	38.7±7.6		0.1462±0.0300		0.1980±0.0416	
Women, Left	Low	58	24.9±6.0	<0.01	0.1007±0.0251	<0.01	0.1326±0.0318	<0.01
	Normal	411	32.9±6.5		0.1361±0.0285		0.1833±0.0381	
	High	116	35.1±5.9		0.1455±0.0260		0.1961±0.0350	
Women, Right	Low	50	25.2±5.7	<0.01	0.1015±0.0242	<0.01	0.1344±0.0308	<0.01
	Normal	444	33.2±6.4		0.1377±0.0280		0.1858±0.0373	
	High	91	36.1±6.2		0.1509±0.0280		0.2044±0.0380	

a. Independent sample t-test

(2) Figure 4 graphically displays the plantar shapes plotted against the average measured arch height and showing ±2SD. Even though mean values differ, there is considerable overlap in measured arch heights among the 3 plantar shapes.

(3) Table 22 shows subjects cross-classified by plantar shape and measured arch height and arch indices. Arch height and the arch indices are separated into the percentile distributions found in the left and right plantar shapes. A "match" was defined as an arch height or arch index in a particular percentile that fell into the same percentile of the plantar shape distributions (right and left foot considered separately). Among the men, the low plantar shape matched with the lowest distributions of arch heights, arch indices, or bony arch indices in 41% to 45% of the cases; the normal plantar shape matched with the middle distributions of arch heights, arch indices, or bony arch indices in 75% to 77% of the cases; the high plantar shape matched with the highest distributions of arch heights, arch indices, or bony arch indices in 24% to 29% of the cases. Among the women, the low plantar shape matched with the lowest distributions of arch heights, arch indices, or bony arch indices in 47% to 52% of the cases; the normal plantar shape matched with the middle distribution of arch heights, arch indices, or bony arch indices in 73% to 80% of the cases; the high plantar shape matched with the highest distributions of arch heights, arch indices, or bony arch indices in 24% to 27% of the cases. For both men and women, the highest distributions of arch heights or arch indices were more likely to be classified as a normal plantar shape (71% to 75% of cases) than a high plantar shape (24% to 29%). The

lowest distributions of arch heights or arch indices were much less likely to be classified as a high plantar shapes (<1% to 2% of cases) and the highest distributions were much less likely to be classified as low (2% to 7% of cases). Overall, arch height was correctly classified by plantar shape 64% of the time for both men and women.

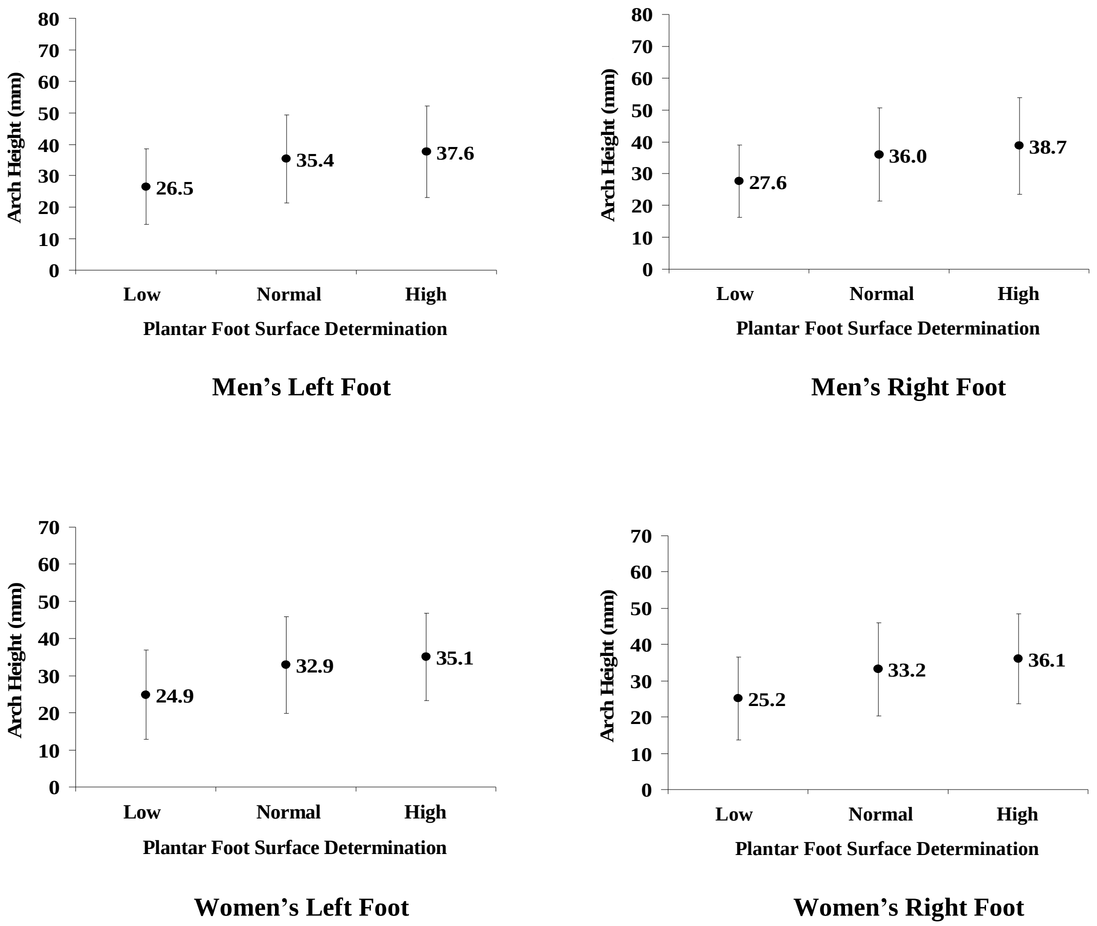

Figure 4. Comparison of Measured Arch Height with Plantar Foot Shape. Mean values are displayed and vertical bars are ±2SD.

Table 22. Classification of Subjects by Plantar Surface Determination and Measured Arch Height and Arch Indices[a]

Variable	Percentiles of Arch Heights and Arch Indices (Based on Distributions of Plantar Shapes)	Low Plantar Shape		Normal Plantar Shape		High Plantar Shape	
		n	%	n	%	n	%
Men							
Arch Height Left	0.1–12.5%	**101**	**45.3**	108	48.4	14	6.3
	12.6–83.7%	119	9.4	**950**	**74.9**	199	15.7
	83.8–100.0%	2	0.7	211	72.5	**78**	**26.8**
Arch Height Right	0.1–11.2%	**82**	**41.0**	106	53.0	12	6.0
	11.3–84.3%	115	8.8	**993**	**76.3**	194	14.9
	84.4–100.0%	3	1.1	209	74.6	**68**	**24.3**
Arch Index Left	0.1–12.5%	**100**	**44.8**	110	49.3	13	5.8
	12.6–83.7%	120	9.5	**948**	**74.7**	201	15.8
	83.8–100.0%	2	0.7	211	72.8	**77**	**26.6**
Arch Index Right	0.1–11.2%	**81**	**40.5**	106	53.0	13	6.5
	11.3–84.3%	118	9.1	**1001**	**76.9**	183	14.1
	84.4–100.0%	1	0.4	201	71.8	**78**	**27.9**
Bony Arch Index Left	0.1–12.5%	**100**	**44.8**	108	48.4	15	6.7
	12.6–83.7%	120	9.5	**949**	**74.8**	199	15.7
	83.8–100.0%	2	0.7	212	72.9	**77**	**26.5**
Bony Arch Index Right	0.1–11.2%	**85**	**42.7**	102	51.3	12	6.0
	11.3–84.3%	114	8.8	**1007**	**77.3**	181	13.9
	84.4–100.0%	1	0.4	198	70.7	**81**	**28.9**
Women							
Arch Height Left	0.1–9.9%	**27**	**46.6**	27	46.6	4	6.9
	10.0–80.2%	29	7.1	**300**	**73.0**	82	20.0
	80.3–100.0%	2	1.7	84	72.4	**30**	**25.9**
Arch Height Right	0.1–8.5%	**24**	**49.0**	23	46.9	2	4.1
	8.6–84.4%	25	5.6	**353**	**79.3**	67	15.1
	84.5–100.0%	1	1.1	68	74.7	**22**	**24.2**
Arch Index Left	0.1–9.9%	**28**	**48.3**	26	44.8	4	6.9
	10.0–80.2%	28	6.8	**302**	**73.5**	81	19.7
	80.3–100.0%	2	1.7	83	71.6	**31**	**26.7**
Arch Index Right	0.1–8.5%	**23**	**46.9**	25	51.0	1	2.0
	8.6–84.4%	26	5.8	**351**	**78.9**	68	15.3
	84.5–100.0%	1	1.1	68	74.7	**22**	**24.2**

Table 22. Classification of Subjects by Plantar Surface Determination and Measured Arch Height and Arch Indices[a] (continued)

Variable	Percentiles of Arch Heights and Arch Indices (Based on Distributions of Plantar Shapes)	Low Plantar Shape		Normal Plantar Shape		High Plantar Shape	
		n	%	n	%	n	%
Bony Arch Index Left	0.1–9.9%	**30**	**51.7**	25	43.1	3	5.2
	10.0–80.2%	26	6.3	**302**	**73.5**	83	20.2
	80.3–100.0%	2	1.7	84	72.4	**30**	**25.9**
Bony Arch Index Right	0.1–8.5%	**25**	**51.0**	23	46.9	1	2.0
	8.6–84.4%	24	5.4	**354**	**79.6**	67	15.1
	84.5–100.0%	1	1.1	67	73.6	**23**	**25.3**

a. Highlighted cells are where the largest agreement might be expected. Arch height and arch height indices are separated into percentiles represented by plantar surface distributions

7. DISCUSSION.

a. The present study demonstrated that prescribing running shoes on the basis of the shape of plantar foot surface did not reduce injury risk in Air Force BMT. In fact, women who wore shoes prescribed for their foot type tended to have a higher injury incidence rate and a higher injury risk in the univariate Cox regression (HR(E/C)=1.23, 95%CI=1.00–1.53). However, the risk among the women wearing the prescribed shoes was reduced in the multivariate model that controlled for other significant injury risk factors (HR(E/C)=1.14, 95%CI=0.89–1.38). Men who wore the prescribed shoe also tended to have higher injury risk than the control men, but this elevated risk was small in the multivariate analysis (HR(E/C)=1.11, 95%CI=0.85–1.55) and similar to that of the women in multivariate analysis.

b. The results of the current study can be compared with the results of a similar Army investigation (86) because the two studies were designed to be complementary; however, there were some important differences mandated by the respective Army and Air Force command groups. Similarities in the studies included 1) tracking of subjects in the same medical surveillance system, 2) calculation of injury indices in an identical manner, 3) the same randomized prospective cohort design with a C group receiving a single stability shoe and an E group receiving a shoe prescribed on the basis of plantar shape. Differences between the studies had to do with 1) the types of shoes, 2) the shoes selected by the E group, and 3) the nature of the training environment. C group subjects in the current Air Force study received a New Balance 498, while C group subjects in the Army study received a New Balance 767ST. E group subjects in the current Air Force study received only 1 of only 3 shoes, one for each foot type. E subjects in the Army study could select from 19 different shoes, as long as the shoe they selected had been designated by running shoe companies as appropriate for their plantar shape. There are also differences in the Army and Air Force program of instruction and length of training (6 versus 9 weeks).

c. Despite the differences in the Army (86) and Air Force studies, the results generally concur. Injury risk was slightly elevated in the group that received a shoe based on plantar shape (E group) when compared with the group that received a stability shoe regardless of plantar shape (C group). Hazard ratio comparisons for the two studies are shown in Table 23.

Table 23. Comparison of Army and Air Force Studies Examining the Efficacy of Prescribing Running Shoes Based on Plantar Surface Prescription

Type of Cox Regression	Study	Group	Men		Women	
			n	Hazard Ratio (95%CI)	n	Hazard Ratio (95%CI)
Univariate	Army	Stability Shoe (C) Prescribed Shoe (E)	1068 1079	1.00 1.02 (0.89–1.17)	464 451	1.00 1.06 (0.90–1.24)
	Air Force	Stability Shoe (C) Prescribed Shoe (E)	913 1042	1.00 1.09 (0.92–1.29)	345 373	1.00 1.23 (1.00–1.53)
Multivariate	Army[a]	Stability Shoe (C) Prescribed Shoe (E)	623 616	1.00 1.11 (0.91–1.34)	242 219	1.00 1.14 (0.91–1.44)
	Air Force	Stability Shoe (C) Prescribed Shoe (E)	610 658	1.00 1.11 (0.89–1.38)	178 187	1.00 1.14 (0.85–1.55)

a. Results are from multivariate model including fitness variables (page 34 of report, reference number 86)

d. As noted earlier, motion control shoes are designed for low-arched individuals to presumably control for excessive pronation; cushioned shoes are designed for high-arched individuals to presumably provide cushioning to reduce ground impact forces and to allow for more foot pronation (25-28). If injury risk could be reduced by prescribing running shoes based on plantar shape, that reduced risk might be best seen by comparing E and C subjects at the extremes; that is, those with high and low arches. This is because E subjects wore shoes specifically designed for their foot type (motion control and cushion), while C subjects wore a stability shoe designed for another foot type. Contrary to expectation, comparing E and C subjects in this manner indicated that injury risk was slightly elevated in the E group. This indicated that even with the extreme foot types, prescribing running shoes based on plantar surface did not reduce injury risk. Again, these results concur with the Army study (86) testing the prescription efficacy as shown in Table 24.

e. All C group subjects wore a stability shoe regardless of plantar shape. Injury risk was similar for all plantar shapes types regardless of the type of shoe worn. There was a tendency for women with low plantar shapes to have higher injury risk, but this subgroup included only 23 subjects. Again, these data generally concur with those from the Army study (86) as shown in Table 25. These data suggest that individuals in basic training can wear a standard stability shoe regardless of plantar shape and the associated injury risk will be as low or lower than if they wore a shoe prescribed on the basis of foot arch height.

Table 24. Comparison of Army and Air Force Studies Including Only High and Low Plantar Surface Individuals (Univariate Cox Regression Analyses)

Study	Group[a]	Men		Women	
		n	Hazard Ratio (95%CI)	n	Hazard Ratio (95%CI)
Army	Stability Shoe (C) Prescribed Shoe (E)	299 295	1.00 1.23 (0.96–1.59)	119 124	1.00 1.16 (0.85–1.58)
Air Force	Stability Shoe (C) Prescribed Shoe (E)	198 315	1.00 1.14 (0.82–1.58)	64 101	1.00 1.23 (0.77–1.94)

a. The Stability Shoe (C) group and Prescribed Shoe (E) group include ONLY individuals with high and low plantar shapes (i.e., individuals with normal plantar shapes are excluded)

Table 25. Comparison of Army and Air Force Studies Including Only C Subjects Who Wore the Stability Shoe Regardless of Plantar Shape (Univariate Cox Regression Analyses)

Study	Plantar Shape	Men		Women	
		n	Hazard Ratio (95%CI)	n	Hazard Ratio (95%CI)
Army	Low Normal High	137 768 162	1.01 (0.76–1.24) 1.00 0.93 (0.70–1.24)	38 345 81	0.74 (0.47–1.18) 1.00 1.05 (0.78–1.41)
Air Force	Low Normal High	79 714 119	1.09 (0.70–1.70) 1.00 1.11 (0.77–1.59)	23 280 41	1.50 (0.83–2.72) 1.00 0.84 (0.50–1,40)

f. Despite the general concurrence between the Army (86) and Air Force investigations, these studies are not in accord with a previous study (29) that showed a postwide decrease in serious injuries at Fort Drum, New York, after initiation of a running shoe prescription program. Methodological differences between the Fort Drum project and the current Air Force study are similar to those previously outlined between the Ft Drum study and the Army footwear study (29). The current Air Force study involved a prescription based only on plantar shape; the Fort Drum study involved a prescription based on an evaluation of foot arch height and foot flexibility. The current Air Force study involved a population of recruits in a situation where there was assurance that the correct shoe was obtained and worn. The Fort Drum study involved Soldiers who were given the shoe prescription, but there was little follow-up to determine whether they had actually purchased and/or worn the recommended shoe. In fact, a survey involving a convenience sample of 122 Fort Drum Soldiers (out of an average 9,752 estimated to be on post) found that only 11% had followed the shoe prescription advice. The current Air Force study involved a prospective shoe prescription involving two groups training side by side in a standardized 6-week program with follow-up for any injury occurring during the period. The Fort Drum study involved a retrospective examination of medical visits to a physical therapy clinic before and after the shoe program was initiated. A number of temporal factors were potential confounders in the Fort Drum study, and these were discussed at length in the report on that study (29). The major potential confounder was the change in the medical surveillance system used to track injuries, which occurred at the exact point when injuries began to decrease. Thus, the current Air Force study involved manipulation of only one variable (running shoe prescription based on plantar shape), provided considerably better knowledge about the shoes worn, and involved a more controlled training environment.

g. As noted in the background section of this paper, it is not clear whether or not gait mechanics differ in high- and low-arched individuals who are not symptomatic or who have not had a prior injury (19-21). There is some evidence that symptomatic individuals or individuals with prior injury may be more likely to have altered gait mechanics (16, 18, 105). We did not obtain the symptomology of the subjects in this study, but they can be assumed to be healthy and relatively symptom-free since they had been initially cleared for BMT in the MEPS. When asked on the questionnaire whether they had had a previous lower limb injury, only 20% (overall) responded positively. However, a global question like this may not capture all subjects with prior lower limb injury: studies comparing injury rates over various recall periods have shown that as the recall period increases, self-reported injury rates decrease (106-108). Nonetheless, the screening procedures and the low positive response to the prior injury question suggest that the number of symptomatic subjects in this study was probably low.

a. <u>Plantar Surface Determination and Measured Arch Height and Arch Indices.</u>

(1) The prescription of running shoes was based on the plantar foot surface evaluation because this method was being used in Army BCT at the time of the study and comparability was desired between the Air Force and Army studies (86). Further, this technique is similar to a common self-evaluation technique (the wet test) recommended by running magazines, shoe companies, and other publications (1, 13-15). This self-evaluation technique is used because plantar shape is presumed to reflect arch height and it is arch height for which running shoe types are presumably designed (1). In the current study, average arch height values did differ among the three plantar shapes with higher plantar shapes reflecting higher arch heights. However, there was considerable overlap in the individual arch height values within the three plantar surface determinations. This concurs with the Army study (86), which had essentially identical findings.

(2) In the current study, over 75% of individuals classified as normal plantar shapes were matched with the middle distribution of measured arch heights. However, there was also a strong bias for those with high and low measured arch heights to be classified as having normal plantar foot surfaces (51% to 76% of cases). In fact, only 24% to 49% of the measured arch heights were correctly matched with the high and low plantar shapes. Moreover, a much lower percentage of the high-arched individuals were correctly classified compared with low-arched individuals.

(3) Comparisons of the two extreme plantar shapes showed much less overlap. High plantar surface cases were seldom found in the lowest measured arch height or arch indices (≤ 7% of cases) and low plantar surface cases were rarely found in the highest of the arch heights or arch indices (≤ 2%). Nonetheless, the bias toward the normal plantar classification brings into question the practice of using plantar surface ratings as a surrogate for arch height when this is used for individual assessment.

b. Foot Arch Height, Foot Indices, and Injuries.

(1) Injury risk was higher among individuals with lower arch heights or lower arch indices when compared with those with normal arch heights or arch indices. In fact, among the women, a low bony arch index was an independent injury risk factor in the multivariate Cox regression analysis. The Army running shoe study (86) demonstrated a trend toward higher risk among men with low arch heights or low arch indices. These results are not in accord with Cowan et al. (4), who showed higher injury risk among high-arched Army infantry recruits and lower risk among low-arched infantry recruits. The results are in partial accord with those of Kaufmann et al. (3), who showed higher injury risk among both high- and low-bony arch indexed Navy Sea, Air, and Land (SEAL) candidates.

(2) Examination of the methodologies of the Cowan et al. (4) and Kaufmann et al. (3) studies might be instructive in accounting for the differences in the findings. Cowan et al. (4) took pictures of the right foot of 246 male infantry recruits while they stood with their weight on that foot. A calibration device was included in the picture frame and pictures were digitized to determine arch heights and foot lengths. Recruits were classified into those with the highest 20% and lowest 20% of 1) arch heights (floor to navicular bone), 2) arch index, and 3) bony arch index. After this evaluation, the recruits participated in the 12-week infantry basic training program. Recruits with the highest arch heights, highest arch index, or highest bony arch index were at the highest risk of a lower extremity injury; lower extremity injury risk was lowest among those with the lowest arch height, arch index, or bony arch index. Compared with the recent Army (86) and current Air Force running shoe studies, Cowan et al. (4) used a different subject population, different methods of arch measurement (pictures versus direct measurements), and a different definition of injury. In addition, recruits trained for a longer time in a different training environment. These methodological differences might account for some of the discrepant findings.

(3) Kaufmann et al. (3) collected bony arch index data on 423 SEAL candidates prior to their 25-week training program. Methods for obtaining the measurements (photographs, direct measures, etc.) were not described and the units of measure were not noted. Compared with those with “normal” bony arch values (20.0–22.8), those defined as pes cavus (> 22.8) or pes planus (< 20.0) tended to have a higher incidence of stress fractures, Achilles tendinitis, and iliotibial band syndrome, although the differences were not statistically significant. The paucity of the methodological description make direct comparisons with the recent Army (86) and

current Air Force running shoe studies difficult. As with Cowen et al. (4), differences in subject populations, length of training time, training environments and injury definitions are likely to account for some of the differences.

(4) Arch height and arch index values in the current study can be compared with those of Cowan et al. (4), since the measures were obtained using the same anatomical landmarks. As shown in Table 26, average values for all three measures of the right foot of the men in the current study were about 30% less than the right foot of the men in the Cowan et al. (4) study. The lower arch heights in the Cowan et al. (4) study may be attributed to placing the entire body weight on one foot as opposed to about half the body weight in the current study (weight was equally distributed on both feet in the current study). Men in the current study generally demonstrated a range of values similar to that of Cowan et al. (4) for all three measures.

Table 26. Comparison of Arch Heights and Arch Indices in the Current Study and in the Study of Cowan et al. (4)

Measure	Level of Measure	Cowen et al. (4) (Men, Right Foot)	Current Study (Men, Right Foot)
Navicular Height (mm)	Mean ± SD	46.0 ± 6.1	35.5±7.8
	20% Lowest	27.2–40.8	12.6–28.5
	60% Middle	40.9–50.8	28.6–41.8
	20% Highest	50.9–60.5	41.9–49.0
Arch Index	Mean ± SD	0.17 ± 0.02	0.13±0.03
	20% Lowest	0.10–0.15	0.05–0.11
	60% Middle	0.15–0.19	0.11–0.16
	20% Highest	0.19–0.24	0.16–0.18
Bony Arch Index	Mean ± SD	0.24 ± 0.04	0.18±0.04
	20% Lowest	0.14–0.21	0.06–0.14
	60% Middle	0.21–0.27	0.14–0.21
	20% Highest	0.27–0.34	0.21–0.25

(5) Table 27 compares the arch height, arch indices and foot length values in the current study with that of the complementary Army running shoe study (86). Anatomical landmarks were identical in the two studies. Average values for the arch height and the arch indices were 7% to 17% lower in the current Air Force study compared with the Army study but the variances (SD) in the two studies was very similar. Average foot lengths and MPJ lengths were very similar in the two studies.

Table 27. Comparison of Arch Heights, Arch Indices, and Foot Lengths in the Current Air Force Study and the Previous Army Study (86)

Measure	Level of Measure	Men				Women			
		Right Foot		Left Foot		Right Foot		Left Foot	
		Air Force	Army	Air Force	Army	Air Force	Army	Air Force	Army
Navicular Height (mm)	Mean ±SD	35.5±7.8	41.4±7.7	34.6±7.6	39.5±8.2	32.9±6.8	37.5±6.9	32.5±6.9	36.3±7.1
	20% Lowest	12.6–28.5	13.8–34.8	12.8–27.9	9.3–32.8	15.5–27.4	16.6–31.7	8.8–26.8	15.3–30.0
	60% Middle	28.6–41.8	34.9–47.6	28.0–40.8	32.9–46.1	27.4–38.5	31.8–42.9	26.9–38.1	30.1–42.1
	20% Highest	41.9–49.0	47.7–69.0	40.9–47.7	46.2–69.0	38.6–44.7	43.0–63.5	38.2–44.2	42.2–59.4
Arch Index	Mean ±SD	0.13±0.03	0.15±0.03	0.13±0.03	0.15±0.03	0.14±0.03	0.15±0.03	0.13±0.03	0.15±0.03
	20% Lowest	0.05–0.11	0.05–0.13	0.04–0.l0	0.03–0.12	0.06–0.11	0.03–0.13	0.04–0.11	0.06–0.12
	60% Middle	0.11–0.16	0.13–0.18	0.10–0.15	0.12–0.17	0.11–0.16	0.13–0.18	0.11–0.16	0.12–0.18
	20% Highest	0.16–0.18	0.18–0.26	0.15–0.18	0.17–0.27	0.16–0.19	0.18–0.27	0.16–0.18	0.18–0.25
Bony Arch Index	Mean ±SD	0.18±0.04	0.21±0.04	0.18±0.04	0.20±0.05	0.18±0.04	0.21±0.04	0.18±0.04	0.20 0.04
	20% Lowest	0.06–0.14	0.06–0.18	0.06–0.14	0.04–0.17	0.08–0.15	0.09–0.18	0.05–0.15	0.08–0.17
	60% Middle	0.14–0.21	0.18–0.25	0.14–0.21	0.17–0.24	0.15–0.22	0.18–0.25	0.15–0.21	0.17–0.24
	20% Highest	0.21–0.25	0.25–0.40	0.21–0.24	0.24–0.39	0.22–0.26	0.25–0.37	0.21–0.25	0.24–0.35
Foot Length	Mean ±SD	26.7±1.3	26.8 ±1.3	26.8±1.3	26.8±1.4	24.2±1.3	24.3±1.3	24.3±1.3	24.3±1.3
MPJ Length	Mean ±SD	19.9±1.1	19.7±1.1	19.9±1.1	19.7±1.1	18.0±1.1	18.9±1.0	18.1±1.2	18.0±1.1

c. <u>Injury Rates in BMT.</u>

(1) Table 28 compares injury incidence and injury rates in the current study with that of a previous Air Force study in which the data was collected about 13 years earlier (8). In the previous study (8), injuries were obtained from a surveillance system called the Sports Medicine and Research Team (SMART) System that tracked outpatient encounters. Injuries were broadly defined and included medical visits for both overuse- and traumatic-type injuries. Examination of injuries included in the SMART system indicated that they were similar to those included in the CII. Thus, the CII was the injury index chosen for comparison with the earlier study. Table 28 shows that the injury rate (CII) for men was 1.64 times higher and the injury rate for women was 1.24 times higher in the current study compared with the earlier study.

Table 28. Comparison of Injury Incidence and Injury Rate in Current Study and that of Snedecor et al. (8)

Study	Year Data Collected	Gender	n	Injury Incidence (%)	Injury Rate (injured Airmen/month)
Snedecor et al.	1994–1995	Men	8,660	16.8	11.2
		Women	5,250	37.8	25.2
Current[a]	2007	Men	1,979	27.6	18.4
		Women	723	46.9	31.3

a. Injury index is the CII

(2) The higher injury rates in the current study could be at least partially due to changes that have occurred in the BMT program of instruction since 1999 in response to changing world conditions. Since 1999 recruits have spent more time training on field security, fighting positions, checkpoint operations, road marching, confidence courses, M-16 rifle, and cover and concealment. Recruits spend more time in the field. A two-day perimeter defense exercise (“Scorpion’s Nest”) has recently been developed and is designed to simulate defense of a fixed airfield in hostile territory. Activities during this exercise include patrolling, defense against infiltration, and area operations under simulated attacks (109-112).

(3) Besides changes in the program of instruction, the Air Force also replaced the cycle ergometer test with the current 1.5 mile running test in 2004. It can be assumed that this increased emphasis on running during BMT. It has been shown that longer running distance is associated with a higher incidence of injury in both military (98, 99) and civilian (113-116) environments

d. Injury Risk Factors. The present study is the first to examine risk factors for injuries in BMT. A number of risk factors previously identified in Army and Marine basic training were also established here.

(1) Physical Fitness.

(a) Higher injury risk was associated with lower aerobic fitness (i.e., slower 1.5-mile run times), as has been found in much of the literature when aerobic fitness is measured with either a maximal effort run (75, 76, 78, 81, 85, 86, 96, 117-119) or VO_2max (81, 120). Importantly, slower run times were independent risk factors when considered in the multivariate model. Lower fit individuals are likely to fatigue more rapidly for both cardiovascular and metabolic reasons (121, 122). Fatigue has been shown to result in changes in economy (123, 124) and gait (123-128), which may put more stress on body regions not accustomed to stress. Individuals with lower aerobic capacity may perceive long-term low intensity tasks as more difficult (129). The combined cardiovascular, metabolic, biomechanical, and perceptual stress could make injuries more likely in these less fit individuals.

(b) Higher injury risk was also associated with lower muscular endurance (push-ups and crunches). Men and the women tended to have higher injury risk at the lowest muscular endurance quartile. Among the men, the relationship between muscular endurance and injury was such that progressively lower performance levels resulted in progressively higher injury risk. These findings are generally in consonance with previous Army (77, 81, 86) data showing a similar relationship. Like aerobic fitness, individuals with lower levels of muscular endurance will be required to work at a larger percentage of their maximal muscular endurance capacity during physical activities in BMT that require this fitness component (e.g., obstacle courses, climbing). In a manner analogous to aerobic fatigue, individuals with lower muscular endurance may perceive a greater level of stress and need to recruit different muscle groups as the active muscle groups begin to fatigue (127, 130, 131). The unaccustomed stress may make injuries more likely.

(2) Height and Weight. In the current study there was no relationship between injury risk and body weight and this is in consonance with other basic training studies that have examined this relationship (81, 86, 132). There was also no association between injury risk and height in the current study. Previous basic training studies examining associations between injury risk and height are conflicting. One study found that shorter Australian Air Force recruits were at higher injury risk (132), while a study of Army recruits found that shorter women, but not shorter men, were at higher risk (78). Another study found no relationship between injury risk and height in Army BCT (81). In multivariate analysis, height was not found to be an independent injury risk factor (132). In the present study and another that found no relationship between height and injury (81), height was collected only to the nearest inch. Studies using finer graduations in centimeters (132) or tenths of centimeters (78) find that shorter individuals are at higher injury risk. Use of finer graduations of height may allow more accurate classification of shorter individuals.

(3) **Body Mass Index.**

(a) In the current study, there tended to be a bimodal relationship between BMI and injury risk among the men: those having both high and low BMI were at increased risk compared with the middle group. Some Army studies also report bimodal relationships among male recruits (78, 86), but others have shown no relationship (77, 81) or increased risk with higher BMI (132). One study of Chinese Armed Forces Police found that those with low BMI were at higher injury risk (133).

(b) In the current study, women with higher BMI tended to be at higher injury risk than those in the middle quartile. A similar trend was reported in one Army recruit study (81), but in studies of female Army recruits (76, 78) and female Marines (134) bimodal relationships have been reported. Another Army study found that women in the lowest decile of BMI tended to be at slightly higher injury risk (86).

(c) There is evidence that BMI has been increasing in Army recruits over the last 30 years (86, 135), but also evidence that the weight gain that accounts for most of the change in BMI (height has changed little) is about evenly distributed between fat and fat-free mass (135, 136). Generally, BMI shows a close relationship with body fat in military and civilian samples, demonstrating correlations on the order of 0.7 (102, 137, 138). However, this means that only about 50% of the variance in BMI is accounted for by body fat. The relationship between BMI and injury in basic training is likely to be complex because individuals can have a high BMI either because of higher body fat or because of higher fat-free mass. If high BMI reflects a larger percentage of body fat relative to height, injury risk might be increased because the additional fat burden would both 1) increase the intensity of physical activity (139) leading to more rapid fatigue and 2) impose additional repetitive stress on the musculoskeletal system. However, body fat has not shown a consistent relationship with injuries in Army BCT (76, 78, 81). In contrast to high BMI, low BMI may reflect a paucity of either fat, fat-free mass, or both. Low BMI may make recruits more susceptible to injury if they lack the muscle mass or strength in the supportive structures (ligaments, bones) required to perform certain physical tasks and overexert or overuse the available muscle mass or supportive structures. Since various studies, including the current one, have demonstrated that both high and low BMIs are associated with injury in basic training (76, 78, 86, 132, 134), a bimodal relationship is most plausible and could probably be demonstrated with larger sample sizes.

(4) Cigarette Smoking.

(a) Both men and women who had smoked cigarettes in the 30 days before BMT were at increased injury risk and cigarette smoking was an independent injury risk factor in the multivariate analysis. Cigarette smoking prior to basic training has consistently been associated with increased injury risk both in US Army BCT (77, 81, 86, 140, 141) and in the army basic training in other countries (118, 142). Further, smoking was associated with injury in infantry soldiers (143) and in other occupational groups (120, 144-150). Among the men in the current study, there was a dose-response relationship such that a greater number of cigarettes/day was associated with higher injury risk. Basic training studies that included various levels of smoking have also demonstrated this dose-response relationship (77, 81, 86, 118, 140).

(b) With regard to the possible mechanisms and the biological plausibility of the association between injury risk and cigarette smoking, there is considerable literature showing that cigarette smoking impairs wound healing (151-155), bone healing (156-160), tissue strength (161-166), and immune function. The immune system is important for wound healing, since macrophages, leukocytes, and lymphocytes regulate various steps in the wound-healing process and remove or assist in removal of damaged tissue (167-170). The macrophages of smokers have lower phagocytic activity, lower responsiveness to bacterial challenge, and reduced gene expression of the proinflammatory cytokines important for tissue healing (171-173).

(c) In BMT, all subjects ceased smoking at the beginning of training; thus the mechanism accounting for the association between smoking and injuries must last into the BMT period. Evidence for the longer-term effects of smoking come from studies on collagen metabolism, skin damage, immune function, and possibly bone tissue. One study (174) followed weekly urinary hyrdoxyproline/creatine levels (indicative of collagen metabolism) from individuals 14 weeks after they ceased smoking. It was estimated (by mathematical modeling) that hydoxyproline/creatine levels would return to the level of nonsmokers in about 71 weeks, among those who had previously smoked ≤ 40 cigarettes/day, while it would take 120 weeks to reach the same level in those who had been smoking > 40 cigarettes/day. Other studies have shown that tobacco users have more than twice the risk of moderate to severe facial wrinkling (indicative of skin damage) compared with nonusers, even after controlling for age, sun exposure, and body mass index (175-177). Smoking reduction (at least 50%) for 6 to 8 weeks prior to surgery has been shown to be associated with an almost threefold reduction in postsurgical complications (at 10 days post-surgery) (178). Immune studies suggest that smoking-induced leukocytosis slowly decreases over time once smoking ceases (179-185). One day to 6 weeks after smoking cessation, the leukocyte count was still elevated (181, 185). Three months after smoking cessation, the neutrophil concentration tended to decrease (180). Leukocyte counts approached the level of nonsmokers the longer it had been since the individual stopped smoking, but men who had quit smoking for 10 years or more still had higher leukocyte counts that nonsmokers in one study (182). Another investigation showed that men and women who had quit smoking for an average of 11 years had counts similar to those who had never smoked (179).

(d) Besides physiological mechanisms, psychosocial factors must also be considered in accounting for the association between cigarette smoking and injury. Air Force recruits who were cigarette smokers had higher scores than nonsmokers on various measures of risk taking. These included greater rebelliousness, less seat belt use, more risky sex, more favorable view of illegal drug use, more alcohol use, more binge drinking, less physical activity, less intake of fruits and vegetables, and greater intake of high-fat foods (186). An overall measure of risk taking was also higher in the Air Force recruit smokers (186). In civilian studies, smokers had more motor vehicle accidents, more traffic violations, less seat belt use, less physical activity, more alcohol consumption, and lower intake of fruits and vegetables (187-189). Heavy smoking (≥ 20 cigarettes/day) is much more likely to be associated with multiple risk behaviors (189). It is possible that this higher risk-taking behavior of smokers manifests itself in the activities of BMT and results in a higher injury rate among smokers.

(5) Physical Activity.

(a) Six items on the questionnaire dealt with physical activity prior to BMT. None of these questions was associated with injury among the men. This is in sharp distinction to other studies of Army and Marine recruits, all of which have shown that higher levels of pre-basic training physical activity reduced injury risk in training (6, 7, 70, 77, 78, 81, 86, 118, 133). The intensity of BMT may be lower than that of Army and Marine basic training and prior physical training on the part of the men may be less associated with injury for this reason.

(b) On the other hand, women who had performed more running/jogging or had been running/jogging for a long period of time before BMT tended to be at lower injury risk. In BMT, subjects perform weight-bearing physical activity primarily in the form of standing (in formation), walking, and running. It seems reasonable that a higher frequency of weight-bearing physical training prior to BMT would result in less susceptibility to injury, especially for women, who have lower fitness levels than men, on average (136). Physical activity has several favorable influences on the body. Physical activity of the proper intensity, frequency, and duration can increase aerobic fitness, muscle strength, connective tissue strength, and general health, and can reduce body fat (190-197). Bone mineral density is higher in physically active individuals (141, 198-202) and higher bone mineral density has been associated with greater weekly physical activity (200). These and other factors may contribute to reducing susceptibility to injury (203).

(6) Marital Status.

(a) Men who were of “other” marital status (divorced, widowed, or separated) tended to have a higher injury than single men. Only five men were in the “other” category and normally this would advise caution in interpreting this association. However, the Army running shoe study (86) also found that men of “other” marital status were at higher injury risk than those who were single and had never been married. It might be assumed that those of “other” marital status might be older and this could be the intervening factor explaining the relationship, since risk was slightly elevated in the oldest subjects. The average age (±SD) of single, married, and “other” men in this study were 21±2, 23±3, and 25±3, respectively ($p<0.01$). However, when age and marital status were jointly included in a multivariate model with injury as the dependent variable, age had minimal effects on the marital status on the hazard ratios, as shown in Table 29.

Table 29. Injury Hazard Ratios for Age and Marital Status (Multivariate Cox Regression)

		Men			Women		
Variable	**Level of Variable**	**n**	**Hazard Ratio (95%CI)**	**p-value**	**n**	**Hazard Ratio (95%CI)**	**p-value**
Age	18–19 years	445	1.00	---	154	1.00	---
	20–24 years	1267	1.11 (0.90–1.38)	0.33	441	1.09 (0.83–1.43)	0.54
	≥ 25 years	160	1.27 (0.90–1.80)	0.17	79	0.95 (0.63–1.44)	0.82
Marital Status	Single	1649	1.00	---	553	1.00	---
	Married	218	1.02 (0.76–1.34)	0.89	113	1.33 (1.00–1.77)	0.05
	Other	5	2.80 (0.89–8.79)	0.08	8	1.53 (0.63–3.72)	0.35

(b) Among the women, those who were married had higher injury risk than single women and marital status was an independent risk factor for injury in the multivariate model. Married female Army recruits have been shown to have higher injury risk in two BCT investigations (75, 86), although a third found this relationship only in the male recruits (96). The most recent Army BCT study also found that married status was an independent injury risk factors in multivariate analysis (86). In some of these past studies, when marital status was stratified by age, the marital status effect was considerably diminished (75, 96). The average ages (±SD) of those who were single, married, and "other" were 21±2, 23±3 and 25±5 years, respectively ($p<0.01$). However, when age and marital status were jointly included in a multivariate model, with injury as the dependent variable, results concurred with the data for men: age had minimal effects on the marital status hazard ratios, as shown in Table 29. Generally, civilian studies have shown that married individuals experience a ***lower*** injury rate than nonmarried individuals (204, 205). The higher injury rate in single individuals in civilian studies has been attributed to higher risk-taking behaviors (205, 206). However, in BMT this is not likely to be the case because all individuals perform the same activities so that a single individual cannot take additional risks. It may be that married individuals who receive emotional and physical support from their partners lack this support in BMT, since contact with their spouse and children is extremely limited. Conversely, it is also possible that married women may experience more stress in BMT due to family pressures and this manifests itself in a higher injury rate mediated by factors like distraction, lack of attention, or other problems.

e. Comparison of Physical Characteristics and Demographics with Previous Air Force Data.

(1) Snedecor et al. (8) reported on the age and physical characteristics of 8,660 men and 5,250 women entering BMT after 1 October 1994 and completing BMT by 30 June 1995. Data in the current study were collected in April through July 2007, about 13 years after the Snedecor et al. investigation (8). A comparison of age and the physical characteristics in the Snedecor et al. study with those of the current study is shown in Table 30. Subjects in the present study were slightly older than in the Snedecor et al. study. Among the men, body weight and BMI were 5.0% and 5.7% higher, respectively, in the current study. Among the women, body weight and BMI were 8.6% and 8.3% higher, respectively, in the present study. Temporal trends indicating an increase in body weight and BMI have been noted in Army data (86, 135) and in national samples (207, 208), supporting the findings in this comparison.

Table 30. Comparison of Physical Characteristics in the Present and Past (1994–1995) Studies

Characteristic	Snedecor et al. Study (8)		Present Study	
	Men	Women	Men	Women
Age (yr)	19.6±2.0	19.6±2.1	21.2±2.3	21.4±2.8
Height (in)	70±3	65±3	70±3	65±3
Weight (lbs)	159±23	128±16	167±23	139±19
BMI (kg/m^2)	22.9±2.8	21.5±2.1	24.2±2.7	23.3±2.7

(2) The Snedecor et al. (8) study also reported on demographics. A comparison of the demographics from that study with those from the current study is shown in Table 31. There was little difference in the racial distribution between the two studies, although the number of women of "other" races is slightly higher in the present study. With regard to educational level, the current study had a smaller proportion of men and women with college experience and more high school graduates. Among the men, the distribution of married and single individuals was similar in the two studies; among the women, the current study had a larger proportion of married individuals than did the previous study.

Table 31. Comparison of Demographics in the Present and Past (1994–1995) Studies

Characteristic	Snedecor et al. Study (8)		Current Study	
	Men (%)	Women (%)	Men (%)	Women (%)
Race				
Black	12.4	20.8	14.6	19.7
White	79.9	72.0	78.0	70.0
Other	7.8	7.1	7.4	10.2
Educational Level				
High School Graduate	82.5	81.2	93.3	92.1
1–4 Years College	16.5	18.4	4.4	6.4
Unknown	1.0	0.4	2.3	1.5
Marital Status[a]				
Single	88.1	87.7	88.3	83.0
Married	11.9	12.3	11.7	17.0

a. "Unknowns" were eliminated from the analysis.

f. <u>Comparison of Physical Characteristics and Lifestyle Variables in Current Study and Army Study.</u>

(1) Table 32 shows a comparison of the average physical characteristics in the current Air Force study with that of the complementary Army study (86) in which the data were collected about the same time. Army men and women tended to be slightly older. This is most likely because the maximum age for entering the Army was recently increased to 42 years (209-211) while the maximum age for entering the Air Force remained at 35 years. About 3% of the Army men and 6% of Army women were over 35 years of age. Army men also tended to be heavier and shorter than their Air Force counterparts, resulting in a higher BMI. Air Force and Army women were similar in their physical characteristics.

Table 32. Comparison of Physical Characteristics in the Current Study and the Army Study

Characteristic	Men		Women	
	Current	Army	Current	Army
Age (years)	21.2±2.3	23.0±4.8	21.4±2.8	23.2±5.6
Height (inches)	70±3	69±3	65±3	64±3
Weight (lbs)	167±23	173±32	139±19	138±23
BMI (kg/m^2)	24.2±2.7	25.5±4.3	23.3±2.7	23.7±3.3

(2) Table 33 compares the current Air Force data with that of the complementary Army study (86) on tobacco use, physical activity, injury history, and other variables. The questionnaire used in both studies was identical and administered about the same time allowing for direct comparisons (Appendix D). Compared with the Air Force recruits, more Army recruits had smoked 100 or more cigarettes in their lives and reported being younger when they began smoking. The prevalence of cigarette smoking ≥ 20 days in the 30 days before basic training was more than twice as high among Army recruits compared with Air Force recruits. Army recruits also rated themselves as less physically active than their peers and reported a lower frequency of 1) exercise or sport, 2) running or jogging, and 3) weight training before basic training. Also, the number of months running/jogging or weight training prior to basic training was shorter for Army recruits. Army recruits reported a lower prevalence of lower limb injuries compared with the Air Force. Among the women, Army and Air Force recruits reported about the same number of menstrual periods in the last year and about the same proportion of recruits had gone 6 months without a menstrual cycle. A much larger proportion of Air Force women had taken birth control pills in the last year. Whereas only 13% of Air Force women had previously been pregnant, over 35% of Army women had been.

Table 33. Comparison of Lifestyle Variables in the Current Air Force Study and the Previous Army Study (86)

Variable	Response Category	Men		Women	
		Air Force Study (% in Category)	Army Study (% in Category)	Air Force Study (% in Category)	Army Study (% in Category)
Smoked 100 Cigarettes in Life?	No Yes	68.1 31.9	46.7 53.3	72.7 27.3	54.9 45.1
Age At Which Started Smoking	Never Smoked 6–9 years old 10–14 years old 15–19 years old ≥ 20 years old	53.3 0.6 11.0 32.3 2.8	32.7 2.6 20.8 38.0 5.8	60.5 0.0 10.8 27.1 1.5	42.1 1.5 22.2 30.5 3.8
Days Smoked Cigarettes in Last 30 Days	None 1–9 days 10–19 days ≥ 20 days	73.8 7.0 4.7 14.9	50.8 10.1 7.7 31.5	77.8 3.5 5.2 13.5	57.3 8.7 5.5 28.5

Table 33. Comparison of Lifestyle Variables in the Current Air Force Study and the Previous Army Study (86) (continued)

Variable	Response Category	Men		Women	
		Air Force Study (% in Category)	Army Study (% in Category)	Air Force Study (% in Category)	Army Study (% in Category)
Self Rating of Physical Activity Compared with Others of Similar Age and Sex	Much Less Active Somewhat Less Active About the Same Somewhat More Active Much More Active	4.9 17.5 43.3 31.6 11.7	8.9 24.6 33.1 25.9 7.3	5.7 18.3 24.8 17.2 5.1	16.7 31.4 26.8 21.6 3.5
Frequency of Exercise or Sports Before Basic Training	≤ 1 time/week 2–4 times/week ≥ 5 times/week	11.3 41.3 19.8	27.7 54.4 18.0	21.3 58.7 20.0	36.9 49.4 13.7
Frequency of Running/Jogging Before Basic Training	≤ 1 time/week 2–4 times/week ≥ 5 times/week	30.0 56.2 13.7	46.1 45.3 8.6	33.1 57.1 9.7	50.4 42.1 7.5
Frequency of Exercise with Weights, in Last 2 Months	≤ 1 time/week 2–4 times/week ≥ 5 times/week	49.1 40.2 10.7	60.7 32.2 7.1	61.9 32.8 5.2	78.7 19.2 2.1
Length of Time Running/Jogging Before Basic Training	Did Not Run or Jog ≤ 1 month 2–3 months 4–6 months ≥ 7 months	5.8 21.8 38.7 11.5 11.5	14.5 41.1 28.7 7.2 8.5	9.6 31.8 39.2 8.8 10.7	18.3 39.5 25.8 7.6 8.8
Length of Time Performing Weight Training ≥ 2 Times/Week	Did Not Weight Train ≤ 1 month 2–3 months 4–6 months ≥ 7 months	39.0 13.9 23.2 9.0 15.0	49.9 14.8 17.9 6.8 10.6	51.9 16.5 15.9 7.0 8.7	71.6 11.1 9.1 3.3 5.1
Prior Lower Limb Injury	No Yes	79.9 20.1	85.2 14.8	78.9 21.1	86.5 13.5
Menstrual Periods Last Year	0 1–9 10–12 >12			4.4 11.2 79.9 4.4	4.9 12.4 78.1 4.5
Gone 6 Months Without a Menstrual Cycle Last Year	No Yes			90.9 9.1	88.9 11.1
Taken Birth Control Pills in Last 12 Months	No Yes			53.0 47.0	69.8 29.5
Months Since Last Pregnancy	Never 1–6 months 7–12 months ≥ 12 months			86.9 1.7 3.1 8.3	64.9 3.5 6.1 25.6

8. CONCLUSIONS.

a. This prospective study demonstrated that prescribing running shoes based on the static weight-bearing plantar foot surface shape had little influence on injury risk in BMT, even after controlling for other injury risk factors. There was little difference in injury rates among those who were prescribed a different type of shoe (motion control, stability, or cushion) based on plantar foot shape and those who received a stability shoe regardless of plantar foot shape.

b. Individuals in the lower 20th percentile of arch heights tended to be at higher risk of injury.

c. Plantar foot shapes judged as low, normal, and high did have progressively higher average arch heights. Despite the higher average values, there were a considerable number of mismatches when plantar shapes were matched with corresponding percentiles of arch heights. Plantar shape determinations matched corresponding percentiles of measured arch heights only about 64% of the time, overall. Normal plantar shapes had the largest numbers of matches (over 75%), with high and low plantar shapes matching only 24% and 49% of the time, respectively.

d. Injury incidence in this study was higher than that of a previous Air Force study conducted about 13 years ago. Changes in the BMT program of instruction involving more physically active training and more running could possibly account for some of this increase.

e. This is the first study examining injury risk factors in US Air Force BMT. In consonance with previous Army data (77, 81, 86) and some Marine data (6, 7), injury risk was higher among men and women who were of lower physical fitness or who were cigarette smokers. In addition, women who were less physically active and/or who were married were at higher injury risk.

9. RECOMMENDATION. If the goal is injury prevention, it is not necessary to prescribe running shoes to BMT recruits based on a visual inspection of the static, weight-bearing plantar shape. Prescribing running shoes to BMT recruits on this basis was no more protective against injury than issuing a single shoe regardless of plantar shape. Other procedures need to be considered to prevent injuries in recruits with lower arch heights, since they are at higher injury risk. It is still recommended that recruits receive a new shoe on entry to BMT, since older shoes have previously been shown to be associated with increase injury risk (70).

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APPENDIX A
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APPENDIX B
REQUEST LETTER

APPENDIX C
APPROVAL TO CONDUCT STUDY

APPENDIX D
LIFESTYLE QUESTIONNAIRE (EXAMPLE)

Physical Training Footwear & Musculoskeletal Injuries: Trainee Survey

PLEASE READ ALL DIRECTIONS AND QUESTIONS CAREFULLY.

- **Answer all questions to the best of your recollection.**
- **Ask research staff for help if you need it.**

About You

1. Today's date: |___|___| / |___|___| / |___|___|___|___|
   MONTH DAY YEAR

2. What is your name? ______________________________________
   (LAST NAME, FIRST NAME, MIDDLE INITIAL)

3. What is your SSN? |___|___|___|-|___|___|-|___|___|___|___|

4. What is your birth date? |___|___| / |___|___| / |___|___|___|___|
   MONTH DAY YEAR

5. Are you…
   - ☐ 1 Male
   - ☐ 2 Female

6. Which service branch are you in?
   - ☐ 1 Air Force
   - ☐ 2 Army
   - ☐ 3 Marine Corps
   - ☐ 4 Navy

7. Prior to entering basic training, what type of shoes did you wear most of the day?
   - ☐ 0 Don't know
   - ☐ 1 Boots
Name or type, _______________
   - ☐ 2 Dress shoes
Name or type, _______________
   - ☐ 3 Women Only: Dress shoes with heels (1" or less)
Name or type _______________
   - ☐ 4 Women Only: Dress shoes with heels (More than 1")
Name or type, _______________

☐5 Running shoes
Name or type, ______________

☐6 Sandals
Name or type, _____________

☐7 Other
Please specify, ____________

Tobacco Use

8. Have you smoked at least 100 cigarettes in your life? (100 cigarettes = 5 packs)

☐1 YES
☐2 NO

9. About how old were you when you smoked a whole cigarette for the first time?
(If you have never smoked a whole cigarette, write 00)

|___|___| Years Old

10. During the past 30 days, on how many days did you smoke a cigarette?
(If you have never smoked or not smoked in the last 30 days, write 00)

|___|___| Days

11. During the past 30 days, on the days you smoked, how many cigarettes did you smoke per day?
(If you have never smoked or not smoked in the last 30 days, write 00)

|___|___| Cigarettes

12. If you used to smoke cigarettes and quit, how many months ago did you quit?
(If you have never smoked, write 00)

|___|___| Months

Physical Activity

13. Compared to others your same age and sex, how would you rate yourself as to the amount of physical activity you performed prior to entering basic training?

☐1 Much less active
☐2 Somewhat less active
☐3 About the same
☐4 Somewhat more active
☐5 Much more active

14. Over the last 2 months, what was the average number of times per week you exercised or played sports for at least 30 minutes at a time?

- ☐0 Never
- ☐1 Less than 1 time per week
- ☐2 1 time per week
- ☐3 2 times per week
- ☐4 3 times per week
- ☐5 4 times per week
- ☐6 5 times per week
- ☐7 6 times per week
- ☐8 7 times or more per week

15. Over the last 2 months, how many times per week did you run or jog?

- ☐0 Never
- ☐1 Less than 1 time per week
- ☐2 1 time per week
- ☐3 2 times per week
- ☐4 3 times per week
- ☐5 4 times per week
- ☐6 5 times per week
- ☐7 6 times per week
- ☐8 7 times or more per week

16. How long were you running or jogging before you entered basic training?

- ☐0 Did not run or jog
- ☐1 1 month or less
- ☐2 2 months
- ☐3 3 months
- ☐4 4 to 6 months
- ☐5 7 to 11 months
- ☐6 1 year or more

17. Over the last 2 months, how often per week did you perform weight training exercises?

- ☐0 Never
- ☐1 Less than 1 time
- ☐2 1 time
- ☐3 2 times
- ☐4 3 times
- ☐5 4 times
- ☐6 5 times
- ☐7 6 times
- ☐8 7 times or more

18. How consistently, 2 or more times per week, have you been performing weight training?

- ☐0 Did not weight train > 2/wk
- ☐1 1 month of less
- ☐2 2 months
- ☐3 3 months
- ☐4 4 to 6 months
- ☐5 7 to 11 months
- ☐6 1 year or more

Injury History

19. Have you ever injured bone, muscle, tendon, ligaments, and/or cartilage in one or both of your lower limbs?

☐1 YES ☐2 NO

20. Did any of these injuries prevent you from participating in your normal physical activities for at least one week?

- ☐0 Does not apply, never been injured
- ☐1 YES
- ☐2 NO

21. Following these injuries, were you able to eventually return to 100% of your normal physical activities?

☐0 Does not apply, never been injured
☐1 YES
☐2 NO

<u>If you are a **man**</u>, stop here and wait for further instructions.

<u>If you are a **woman**</u>, complete questions 21 through 25 on the following page.

Women Only: Menstrual History

22. At what age did you start to menstruate?
(If you have not had a menstrual cycle, write 00)

|___|___| Years

23. Over the last 12 months, how many menstrual periods did you have?
(If you have not had a menstrual period, write 00)

|___|___| Menstrual Periods

24. During the last 12 months, have you ever missed six or more <u>months in a row</u> between menstrual cycles?

☐0 N/A, I have never had a menstrual period
☐1 No, I have never missed 6 or more months in a row between menstrual cycles
☐2 Yes, I have missed 6 months or more in a row between menstrual cycles

25. In the last 12 months, have you taken birth control pills or any other hormonal therapy?

☐1 YES
☐2 NO

26. If you have ever been pregnant, how many months ago were you last pregnant?
(If you have never been pregnant, write 00)

|___|___| Months

Stop here and wait for further instructions from the staff.

APPENDIX E
ACKNOWLEDGEMENTS

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