Meta-analysis of Cigarette Smoking and Musculoskeletal Injuries in Military Training

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1Department of Preventive Medicine, Womack Army Medical Center, Fort Bragg, NC; 2Preventive Medicine Branch, Walter Reed Army Institute of Research, Silver Spring, MD; 3ManTech Advanced Systems International, Inc., Herndon, VA; and 4Department of Public Health, College of Education and Health Services, Benedictine University, Lisle, IL

ABSTRACT

BEDNO, S. A., R. JACKSON, X. FENG, I. L. WALTON, M. R. BOIVIN, and D. N. COWAN. Meta-analysis of Cigarette Smoking and Musculoskeletal Injuries in Military Training. Med. Sci. Sports Exerc., Vol. 49, No. 11, pp. 2191–2197, 2017. Purpose: Tobacco use is common among military personnel, as is musculoskeletal injury during training. In a review of the literature on musculoskeletal injuries, there was mixed evidence on the role of smoking as a risk factor. The purpose of this study is to review and analyze the literature on the impact of cigarette smoking on lower-extremity overuse injuries in military training. Methods: We performed a literature search on articles published through October 2016. Search terms focused on lower-extremity overuse musculoskeletal injuries and cigarette smoking in military populations. We conducted a meta-analysis overall and by sex, including smoking intensity. Results: We identified 129 potential studies and selected 18 based on quality. The overall rate ratio for smoking was 1.31, 1.31 for men, and 1.23 for women. Overall and for each sex, rate ratios were significantly greater than 1.0 for each intensity level of smoking. Conclusions: Smoking is a moderate risk factor for musculoskeletal injury and may account for a meaningful proportion of injuries among men and women due to the high prevalence of smoking and injury in this population. Although enlistees are not allowed to smoke during basic training, their risk of injury remains high, indicating that smokers may remain at increased risk for medium- to long-term duration. Key Words: TOBACCO, MUSCULOSKELETAL, EPIDEMIOLOGY, POLICY

Tobacco use and musculoskeletal injuries are two of the most important public health problems affecting the US military. Tobacco use is the single largest preventable cause of disease and premature death in the United States and use is higher among military service members compared with their civilian counterparts (8). Approximately 32% of active duty service members report using tobacco (women, 15%; men, 34.5%) (39). Tobacco use is associated with a myriad of health problems, including heart disease, pulmonary disease, many types of cancer, adverse reproductive outcomes, and worsening of other preexisting health conditions. In the context of musculoskeletal injuries, cigarette smoking has been associated with tissue hypoxia, decrease in wound healing, impairment of blood flow, and a higher rate of postoperative healing complications (18,26,27,33).

Injuries have historically been the leading cause of morbidity among US service members (19). Lower-extremity overuse injuries are particularly burdensome to military service members and have been among the top injuries leading to limited duty days (32). Overuse injuries are common and have been most frequently studied in the basic combat training (BCT) environment (11). Overuse injuries are those injuries associated with running, overtraining, overexertion, repetitive movements and activities, vibratory forces, and prolonged static positioning (14). Lower-extremity overuse injuries may account for up to 75% of injuries among men and 78% among women in BCT (25). Women have about twice the risk of musculoskeletal injury compared with men (5,23).

A number of published studies have explored the relationship between cigarette smoking and the risk of overuse injuries, especially among military populations. However, to our knowledge, no summary of the findings of individual research publications has been conducted. Some studies have reported significant associations (1,20,23), whereas others have not noted such a relationship (34,38). Evaluation of the literature is complicated by the fact that different measures of exposure and endpoint have been used, and different demographic and lifestyle variables simultaneously evaluated. Although Bulzacchelli et al. (7) published a review of risk factors for injury among soldiers in BCT, the review was limited to the first 70 d of
military service. The authors concluded that there was “strong evidence of increased risk” among men, but only “mixed” evidence among women. The article provided no overall quantification of the level of increased risk associated with smoking for men or women (7).

Although each soldier is evaluated for tobacco use during their primary care and most specialty medical appointments, there are no specific recommendations against cigarette smoking or tobacco use regarding the potential effects on training-related injuries. The purpose of this study was to conduct a structured review of the published literature on the impact of cigarette smoking on the risk of lower-extremity overuse injuries in military training (from this point referred to as “training injuries”). Because injury risk is much higher among military women, whereas the prevalence of smoking is higher among men, analyses were stratified by sex.

METHODS

Search criteria. A literature search was conducted of the Cumulative Index of Nursing and Allied Health Literature (CINAHL), Public/Publisher MEDLINE (PUBMED), and Psychological Information Database (PSYCHINFO) databases using terms listed below. A variety of search terms were explored; some returned an unusable number of hits. The final search terms used were:

(musculoskeletal injuries OR overuse injuries OR lower-extremity injury OR stress fractures OR hip fractures OR muscle strain OR knee pain)

AND

(cigarette smoking OR tobacco OR smoking OR cigarettes)

AND

(military OR Army OR Navy OR Soldier OR Marines)

NOT

(smokeless tobacco OR motor vehicle accidents OR risk taking behavior OR burns OR addiction OR cessation OR withdrawal OR memory loss OR carpal tunnel OR osteoporosis).

Limits applied were English language publications, age groups (adults ages 19–44 yr, the age group with data available that is closest to the recruit population, generally 18 to 35 yr). Review articles were excluded. The dates of publication were January 1980 through October 2016. We also searched Google Scholar and references of the articles to ensure any other relevant literature was captured, that potentially met our criteria.

Data abstraction. We performed an initial screening of abstracts, and those that did not meet the inclusion criteria were eliminated based on the abstract alone. The remaining articles were reviewed using a hybrid form that included the article abstract, and also classified the article (see document, Supplemental Digital Content 1, Hybrid form, http://links.lww.com/MSS/A968). Data were entered into the hybrid form, and reviewed by at least one other person before an article was removed from consideration. After a review of all of the hybrid forms, more articles were eliminated as not being relevant.

FIGURE 1—Flowchart of screened and included studies.

Article quality evaluation. Two of us (S.A.B. and D.N.C.) used a data abstraction tool (available upon request), modified from a tool used in Bullock et al. (6). Each reviewer evaluated a series of characteristics and assigned a quality (objective) score. Characteristics reviewed include the research question, source of subjects (inclusion, exclusion criteria), measurement of exposures/risk factors, study design, data on confounders and covariates, statistical methods, whether incidence rates, risks, or odds were used appropriately, use of confidence intervals or P values, multivariable methods, and inclusion of risks or rates for relevant confounders or demographics, with scores from 0 to 14 possible. Each of us (S.A.B. and D.N.C.) also assigned a Subjective Overall Article Quality score based on the overall impression of each article. Each article was rated as 0, unacceptable; 1, acceptable; 2, good to excellent.

Specific threshold scores were not established. Instead, the reviewers evaluated the articles based on subjective and objective criteria. After all the articles were reviewed and the data abstracted to a spreadsheet, the scoring by S.A.B. and D.N.C. were compared. If there were differences in opinion in the suitability score (if only one author scored the article as unacceptable), the authors further discussed the article and
<table>
<thead>
<tr>
<th>Study Citation</th>
<th>Study Design</th>
<th>Study Population*</th>
<th>Population Size</th>
<th>Cigarette Smoking (Definition)</th>
<th>Controlled Variables</th>
<th>Injury Endpoint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altarac et al. (2000)</td>
<td>Cohort</td>
<td>Army basic combat trainees</td>
<td>915 Men</td>
<td>Smoked in last month yes/no. Average smoked per day in past month: did not smoke 1/2 pack or less 1/2–1 pack &gt;1 pack</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1087 Women</td>
<td></td>
<td>Sex, age, race, fitness/activity, BMI/BF%, SES/Ed</td>
<td>Any overuse injury</td>
</tr>
<tr>
<td>Anderson et al. (2015)</td>
<td>Cross-Sectional</td>
<td>Army light infantry brigade soldiers</td>
<td>2101 Men</td>
<td>Smoked at least 100 cigarettes in lifetime AND at least 1 in last 30 d from survey</td>
<td>Age, race, fitness/activity, BMI/BF%, Rank, MOS</td>
<td>Any injury</td>
</tr>
<tr>
<td>Bedno et al. (2013)</td>
<td>Cohort</td>
<td>Army basic combat trainees</td>
<td>8456 Men</td>
<td>Smoking yes/no</td>
<td>Age, race, fitness/activity, BMI/BF%</td>
<td>Any overuse injury</td>
</tr>
<tr>
<td>Cowan et al. (2011)</td>
<td>Cohort</td>
<td>Army basic combat trainees</td>
<td>7323 Men</td>
<td>Smoking yes/no</td>
<td>Age, race, fitness/activity, BMI/BF%</td>
<td>Any overuse injury</td>
</tr>
<tr>
<td>Cowan et al. (2012)</td>
<td>Cohort</td>
<td>Army basic combat trainees</td>
<td>1568 Women</td>
<td>Smoking yes/no</td>
<td>Age, race, fitness/activity, BMI/BF%</td>
<td>Stress fracture, MSI without Stress Fracture</td>
</tr>
<tr>
<td>Heir et al. (1997)</td>
<td>Cohort</td>
<td>Norwegian army recruits—males</td>
<td>480 Men</td>
<td>Current cigarettes per day 0 1–10 &gt;10</td>
<td>Age, race, fitness/activity, BMI/BF%</td>
<td>Any overuse injury</td>
</tr>
<tr>
<td>Henderson et al. (2000)</td>
<td>Cohort</td>
<td>Army combat medic trainees</td>
<td>439 Men</td>
<td>Smoking yes/no</td>
<td>Sex, age, race, fitness/activity, BMI/BF%, alcohol, previous injury</td>
<td>Any injury (most were overuse injuries)</td>
</tr>
<tr>
<td>Jones et al. (1993)</td>
<td>Cohort</td>
<td>Army infantry trainees</td>
<td>303 Men</td>
<td>Smoking yes/no</td>
<td>Age, race, fitness/activity, BMI/BF%, previous injury</td>
<td>Any overuse injury</td>
</tr>
<tr>
<td>Knapik et al. (2001)</td>
<td>Cohort</td>
<td>Army basic combat trainees</td>
<td>733 Men</td>
<td>Smoking yes/no</td>
<td>Sex, age, race, fitness/activity, BMI/BF%</td>
<td>Unspecified Injury Index</td>
</tr>
<tr>
<td>Knapik et al. (2003)</td>
<td>Cohort</td>
<td>Army basic combat trainees</td>
<td>2689 Men</td>
<td>No. days smoked in 30 d before BCT (1–9, 10–19, ≥20)</td>
<td>Sex, age, BMI, fitness/activity, component, education, marital status</td>
<td>Unspecified Injury Index</td>
</tr>
<tr>
<td>Knapik et al. (2010)</td>
<td>RCT</td>
<td>Air Force basic military trainees</td>
<td>2167 Men</td>
<td>Cigarettes smoked in past 30 d (1–9, ≥10)</td>
<td>Unspecified injury, component, age, BMI, education, shoe prescription group</td>
<td>Unspecified Injury Index</td>
</tr>
<tr>
<td>Knapik et al. (2013)</td>
<td>Cohort</td>
<td>Army military police trainees</td>
<td>1838 Men</td>
<td>smoked ≥100 cigarettes in past 7 days</td>
<td>Age, sex, fitness/activity, previous injury, BMI, smoking, tobacco use</td>
<td>Comprehensive Injury Index</td>
</tr>
<tr>
<td>Munnoch and Bridger (2007)</td>
<td>Cohort</td>
<td>Royal Marine Recruits (UK)</td>
<td>1115 Men</td>
<td>Smoking status reported on entry to training. No. smoked per day (1–9, 10–19, 20+)</td>
<td>Age, fitness, BMI, weight, height, educational test scores</td>
<td>Any injury</td>
</tr>
<tr>
<td>Reynolds et al. (1994)</td>
<td>Cohort</td>
<td>Army infantry soldiers</td>
<td>181 Men</td>
<td>Smoking within last year, no. per day and length of time per day (1–10, &gt;10)</td>
<td>Age, BMI, fitness</td>
<td>Any injury (most were overuse injuries)</td>
</tr>
<tr>
<td>Ross and Woodward (1994)</td>
<td>Case-control</td>
<td>Royal Australian Air Force trainees</td>
<td>8644 Combined men and women</td>
<td>Smoking yes/no</td>
<td>Sex, age, fitness/activity, BMI/BF%, integrated training, lower-leg deformity, training season</td>
<td>Any overuse injury</td>
</tr>
<tr>
<td>Taanila et al. (2010)</td>
<td>Cohort</td>
<td>Finnish Defence Forces basic trainees</td>
<td>944 Men</td>
<td>Ever smoked (regularly, never smoked regularly)</td>
<td>Age, fitness/activity, BMI/BF%, alcohol, SES/Ed, previous injury, medication, chronic disease</td>
<td>Any overuse injury, Any overuse injury 10+ days lost</td>
</tr>
<tr>
<td>Taanila et al. (2015)</td>
<td>Cohort</td>
<td>Finnish Defence Forces basic trainees</td>
<td>1411 Men</td>
<td>Ever smoked (regularly, never smoked regularly)</td>
<td>Age, SES/Ed, Company, BMI/Fitness, alcohol, chronic illness, previous injury/surgery</td>
<td>Any overuse injury, any overuse injury 7+ days lost</td>
</tr>
<tr>
<td>Trone et al. (2014)</td>
<td>Cohort</td>
<td>Marine Corps basic training recruits</td>
<td>899 Men</td>
<td>Smoking yes/no 30 d per day (1–9, ≥10)</td>
<td>Sex, age, branch of military, age at menarche</td>
<td>Musculoskeletal overuse injury index</td>
</tr>
</tbody>
</table>

BMI, body mass index; Ed, education; MOS, military occupational specialty; MSI, musculoskeletal injury; RCT, randomized controlled trial; SES, socioeconomic status.
Component, Active Army, National Guard, or Army Reserve.
*Unless indicated, study population is from the United States.
negotiated agreement. Forest plots were generated using R (R Core Development Team, Version 3.1.2) with both the point estimate and 95% confidence interval presented. Plots were generated for smoking yes/no, and for levels of smoking compared with no smoking, overall and stratified by sex.

**Meta-analysis of smoking/no-smoking groups.** Individual study data that met criteria were pooled using meta-analytical techniques. Meta-analyses involving response outcomes were based on hazard or risk rate ratios (RR) for smoking compared with nonsmoking. If only the odds ratios were reported, where possible the RR was calculated from the data presented in the article (12). The results of individual studies were pooled using both random-effect and fixed-effect models, and weighted RR with the corresponding 95% confidence limits (CL) generated and reported as RR with 95% lower limit, upper limit. The meta-analytical technique is used to combine the risk or hazard ratios, where the ratio, standard error, and sample size for each group are known. The weight given to each study was determined by the inverse of the variance of its estimate of effect. All statistical analyses were carried out using R “meta” package.

**Meta-analysis of dose–response.** Because different measures of smoking intensity were reported (e.g., packs per day, number per day), a nonparametric approach to assessing dose–response was used, with levels characterized as none, low, medium, high, and highest. The referent group for each data point was nonsmokers, and a rank-order was assigned to each of the levels of smoking (lowest, medium, highest) as described in each article. The results are interpreted as the RR for injury given the level of smoking, compared with the nonsmoking group, and as a measure of dose–response. Tests of heterogeneity were conducted overall and separately for men and women.

**RESULTS**

The search yielded 129 initial studies and 87 were excluded based on title alone (Fig. 1). Forty-two studies underwent quality review, and we excluded 28 based on established criteria. We considered six additional articles after 2013. Two were rated as good to excellent and retained. We included 18 studies in our final analysis (Table 1).

Of the 26 measures of smoking as yes/no reported from 18 studies evaluated (Fig. 2), the RR for injury associated with smoking ranged from 0.74 to 3.10, with a median value of 1.33. Twenty-four (92%) had a point estimate greater than 1.00 (regardless of significance), and 19 (73%) had a lower CL greater than 1.00. Most of the data points (14) were based on men, 11 were based on women, and one combined men and women.

Overall and for each sex, there was some degree of heterogeneity, with $I^2$ of 47% overall, 56.7% for men, and, 16.2% for women. Based on the Cochrane Handbook guidelines (17), the $I^2$ for men could represent moderate to substantial heterogeneity.

![FIGURE 2—Smoking and musculoskeletal injury in military training. CI, confidence intervals; HR, hazard ratio; N: number of subject; *1, any MSI; 2, stress fracture; 3, overuse injury; 4, time loss injury; 5, any index injury (installation index injury [III], modified installation index injury [MIII], training injury index [TII], comprehensive injury index [CII], overuse injury index [OII]); 6, self-reported injury; 7, medical records injury; 8, women; 9, men.](http://www.acsm-msse.org)
heterogeneity, whereas overall, and for women, it could represent moderate heterogeneity.

There were no substantive differences between the fixed effects and random effects models and only fixed effects results are presented. The weighted average RR between smoking (yes/no) and injury across all data points was 1.31 (1.26–1.36), with a fixed effects model. For both men and women, smoking was significantly associated with injury, with RR of 1.31 (1.26–1.36) and 1.23 (1.11–1.36), respectively.

Nine studies provided 14 data points for levels of smoking, nine for men, and five for women. When the level of smoking was considered (Fig. 3 and Table 2), overall and for men and women, each level had a RR significantly greater than 1.0, compared with nonsmokers. There was a significant linear overall trend between level of smoking (dose) and injury (response) (Cochran–Armitage trend test $Z = 16.8462$, $P < 0.001$). The increase in risk for the lowest level of smoking was 43% for women and 26% for men; the increase for the highest level was 56% for women and 84% for men.

DISCUSSION

The implication for persons entering the military, and most likely, persons beginning any new strenuous activity is that smoking is a preventable risk factor for overuse musculoskeletal injury. Although prevalence of smoking has decreased overall, smoking remains higher among active duty service members (35% among active duty men younger than 25 yr, the age of most accessions) (39) compared with 19% of civilians (3) and is a modifiable risk factor for a range of medical conditions among military personnel, including not just musculoskeletal injury, but also mental health disorders (13).

This review provides a wider scope than the report by Buzacchelli et al. 2014 (8) in that it is not restricted to the first 70 d of military service, a quantified estimate of effect separately for both men and women, and includes a measure of intensity of smoking. This review indicates that smoking is a consistent moderate risk factor for overuse injury among military personnel of both sexes during training.

When considered as a dichotomous variable, the additional risk associated with smoking is about 37% over nonsmokers. A dose–response was apparent as risk of injury increased with increasing smoking intensity, every level above baseline had a RR statistically significant greater than 1.0. At the highest levels, among men, this risk is 1.87 times baseline, and among women, the risk is 1.56 times baseline. The biologically significant linear overall trend between level of smoking (dose) and injury (response) (Cochran–Armitage trend test $Z = 16.8462$, $P < 0.001$). The increase in risk for the lowest level of smoking was 43% for women and 26% for men; the increase for the highest level was 56% for women and 84% for men.

FIGURE 3—Smoking levels and musculoskeletal injury in military training for men and women.

TABLE 2. Association between levels of smoking and musculoskeletal injuries in military training relative to nonsmokers.

<table>
<thead>
<tr>
<th>Sex</th>
<th>Smoking level</th>
<th>RR</th>
<th>95% CL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combined</td>
<td>1 (lowest)</td>
<td>1.27</td>
<td>1.16–1.39</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1.37</td>
<td>1.25–1.49</td>
</tr>
<tr>
<td></td>
<td>3 (highest)</td>
<td>1.71</td>
<td>1.47–1.99</td>
</tr>
<tr>
<td>Male</td>
<td>1 (lowest)</td>
<td>1.25</td>
<td>1.14–1.40</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1.36</td>
<td>1.23–1.49</td>
</tr>
<tr>
<td></td>
<td>3 (highest)</td>
<td>1.94</td>
<td>1.50–2.25</td>
</tr>
<tr>
<td>Female</td>
<td>1 (lowest)</td>
<td>1.30</td>
<td>1.09–1.56</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1.43</td>
<td>1.14–1.80</td>
</tr>
<tr>
<td></td>
<td>3 (highest)</td>
<td>1.56</td>
<td>1.25–1.96</td>
</tr>
</tbody>
</table>

n = number of studies evaluated.
plausible significant dose–response increases our confidence that the findings are valid.

The strengths of this review include that many studies of smoking and injury have been conducted among military populations during training, providing a solid base of knowledge. Military training populations are unique in that trainees are very heterogeneous in terms of sex, age, race, fitness, and other characteristics, while their exposures in training are very similar. Demographic characteristics and medical encounters are well measured.

The weaknesses of this review include: that not all smoking exposures and endpoints were measured the same, and not all studies controlled for factors that could be important confounders (e.g., fitness, body mass index, heavy alcohol use). However, the consistency and significance of the weighted analysis strengthen the argument that smokers are at increased risk of musculoskeletal injury. This association is found among both men and women, and there is also a dose–response between level of smoking and risk of injury.

Because both smoking and musculoskeletal injuries are so prevalent, smoking adds a substantial public health burden, impacting not just the individuals, but also military health care and military training systems. All military branches have tobacco control and use policies, and initial entry military trainees are banned from using tobacco. Given the close supervision exercised over basic trainees, there is little doubt that both the proportion of individuals and the intensity of smoking is substantially reduced from before military entrance. However, it is acknowledged that this ban is not 100% effective. Because trainees continue to be at increased injury after presumably quitting, it is likely that smoking produces a medium- to long-term effect on bone and muscle physiology (29,35).

Future studies on tobacco use and musculoskeletal injuries in military training should include specific questions on past and current smoking, including different types and quantities of tobacco use (i.e., smokeless tobacco and e-cigarettes). Tobacco use documentation in electronic health encounters should be comprehensive and searchable so that future studies can better evaluate associations between tobacco use and injuries. These studies should also include questions related to potential confounders of tobacco use, including alcohol use.

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The results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation and do not constitute endorsement by ACSM.

Conflict of interest: Material has been reviewed by the Walter Reed Army Institute of Research and Womack Army Medical Center. There is no objection to its presentation and/or publication. The opinions or assertions contained herein are the private views of the authors, and are not to be construed as official, or as reflecting true views of the Department of Defense, Department of Army, US Army Medical Department or the US Government.

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