# Predicting Lower-Extremity Injuries Among Habitual Runners

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• **This prospective study of 583 habitual runners used baseline information to examine the relationship of several suspected risk factors to the occurrence of running-related injuries of the lower extremities that were severe enough to affect running habits, cause a visit to a health professional, or require use of medication. During the 12-month follow-up period, 252 men (52%) and 48 women (49%) reported at least one such injury. The multiple logistic regression results identified that running 64.0 km (40 miles) or more per week was the most important predictor of injury for men during the follow-up period (odds ratio = 2.9). Risk also was associated with having had a previous injury in the past year (odds ratio = 2.7) and with having been a runner for less than 3 years (odds ratio = 2.2). These results suggest that the incidence of lower-extremity injuries is high for habitual runners, and that for those new to running or those who have been previously injured, reducing weekly distance is a reasonable preventive behavior.**

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The health benefits of regular exercise have been documented extensively.[1,2] However, relatively little information has been available on the rates of musculoskeletal injuries associated with participation in aerobic exercise,[3-5] and the biologic and behavioral risk factors for musculoskeletal injury have not been clearly identified. The paucity of such information hinders a comprehensive understanding of the overall health effects of regular exercise.

**See also p 2561.**

Running, one of the most common forms of aerobic exercise, is widely perceived to be beneficial to the cardiovascular system but potentially harmful to the musculoskeletal system. Among habitual runners, injuries to the lower extremities seem to be particularly common.[6-11] A relatively high incidence of injury is not surprising, since the running gait involves 50 to 70 footstrikes per minute, each with a force of three to eight times the runner's body weight, depending on the running terrain.[12] Previous studies have reported annual rates of injuries for runners ranging from 24% to 65%,[6,7,11,13,14] but these studies are difficult to compare because they have used recall data, have had small, select groups of subjects, and have used varied definitions of injuries. As a consequence, the rate of lower-extremity injury for habitual runners appears to be substantial, but neither incidence rates nor risk factors have been clearly established.

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Clinical series have suggested several factors that may increase the risk of injury for runners. Among these are female sex, older age, larger body size (height and weight), recent previous injury, high weekly running distance, high-speed running, abrupt change in running habits, lack of experience in running, not warming up, and running on hilly terrain or hard surfaces.[15] Although these factors may characterize runners who seek medical care for injuries, only high weekly distance has consistent support in the epidemiologic literature.[6-8,11,13]

This investigation ascertained the 12-month incidence of running-related lower-extremity injuries among a cohort of habitual runners and examined baseline behavioral and biologic factors associated with these injuries.

## SUBJECTS AND METHODS

### Study Participants

The Physical Fitness Office of the South Carolina Department of Health and Environmental Control, Columbia, provided a mailing list of persons who wished to be notified of road races in the state. A consent form and an 18-page questionnaire were mailed to each person on this list. We used this baseline questionnaire to obtain information on current and past running practices, history of injuries and illnesses, and demographic characteristics. Runners who returned the questionnaire and agreed to participate in the follow-up portion of the study were sent a log and a newsletter each month for the next 12 months. The log contained information on daily running habits, participation in other physical activities, and health problems (including injuries) that occurred during the month.

### Injury Definition

The outcome measure for this analysis was a self-reported "muscle, joint or bone problem/injury" of the lower extremities (foot, ankle, Achilles tendon, calf, shin, knee, thigh, or hip) that the participant attributed to running. The problem had to be severe enough to cause a reduction in weekly distance, a visit to a health professional, or the use of medication.

### Risk Factors

In addition to age and sex, several other possible risk factors were obtained from the baseline data and considered in this analysis. "Previous injury" was defined as a new problem, regardless of cause, in the foot, ankle, Achilles tendon, calf, shin, knee, thigh, or hip, that occurred during the previous 12 months and had been reported on the baseline questionnaire. The injury must have been severe enough for the runner to consult a physician or reduce weekly distance.

We used the following formula to create a body mass index (BMI) for men: $BMI = weight/height^2$, where weight is measured in kilograms and height in meters. For women, the formula was $BMI = weight/height^{1.5}$, where weight is measured in kilograms and height in meters. Height and weight were also examined independently from BMI as predictors of injury. Because other work[16] has shown that BMI has a U-shaped relationship to injury, we created two indicator variables. The BMI-high was identified as those "at or over the 75th percentile," and BMI-low was identified as those "at or below the 25th percentile" for both male and female groups. The

Table 1.—Means, SDs, and Ranges for Continuous Variables for 583 Men and Women Runners

| Variable | Men (N=485) | | | Women (N=98) | | |
|---|---|---|---|---|---|---|
| | Mean | SD | Range | Mean | SD | Range |
| Age (in 1985), y | 41.6 | 9.5 | 13-75 | 36.1 | 8.2 | 22-64 |
| Body mass index | 23.0 | 2.2 | 16.5-31.0 | 25.8 | 2.4 | 20.2-34.6 |
| Height, cm | 178.6 | 6.5 | 154.9-195.6 | 164.3 | 6.0 | 149.9-180.3 |
| Weight, kg | 73.6 | 8.7 | 39.6-104.6 | 54.5 | 6.1 | 40.9-76.4 |
| Running experience, y | 8.7 | 5.8 | 1-37 | 6.2 | 3.3 | 0-14 |
| Running patterns for preceding 3 mo | | | | | | |
| Weekly distance, km (miles) | 38.9 (24.3) | 23.2 (14.5) | 3.2-156.8 (2-98) | 36.8 (23.0) | 22.7 (14.2) | 3.2-112.0 (2-70) |
| Pace, min/km | 4.9 (7.9) | 0.6 (0.9) | 3.4-7.5 (5.5-12) | 5.4 (8.7) | 0.7 (1.1) | 4.3-8.7 (7-14) |
| Frequency, d/wk | 4.5 | 1.4 | 1-7 | 4.8 | 1.4 | 1-7 |

reference group comprised those between the 25th and 75th percentiles.

From the baseline questionnaire, we obtained information on the average weekly distance, average days of running per week, usual terrain, and usual surface for the 3 months before the study. Runners who reported that they ran "most of the time" on rolling or steep hills were classified in the high-risk group for terrain. Runners who ran more than two thirds of the time on concrete were classified in the high-risk group for surface. Two potential risk factors concerning the time of the run were identified: running more than two thirds of the time in the dark and running more than two thirds of the time in the morning. Because of the medical literature's inconsistency regarding the benefit of appropriate preexercise activities, specifically stretching, we created a measure in which the high-risk group consisted of those who stretched more than two thirds of the time before running, whereas those who did some other type of preexercise activity or none at all formed the reference group.

### Statistical Analysis

Our analysis of the data included descriptive statistics of all the variables by sex. The age-adjusted individual association of each potential risk factor to the outcome variable (a lower-extremity injury during the 12-month follow-up) was examined by including age in the logistic regression model. Multiple logistic regression models[17,18] were used to assess the effect of several baseline risk factors on the incidence of lower-extremity injuries during the 12 months of observation. All computer analyses were done with the SAS programming package.[19]

## RESULTS

Of the 1576 baseline questionnaires mailed, 3 were returned for improper addresses. From the 1573 potential respondents, 966 questionnaires were returned (61% response rate). A telephone survey of 100 randomly selected nonrespondents indicated that only 53% were runners and were thus eligible to participate in the study. If we assume that the remaining 507 nonrespondents were also eligible at the same rate, the estimated response rate for the runners was 75%. Although this response rate is lower than we would have liked, it is similar to the rates experienced in similar studies.[6] The demographic characteristics for the 53 eligible nonparticipants who were surveyed by phone indicated that they were slightly younger than the respondents (36.3 years compared with 39.4 years). Both groups had the same average weekly distance (35 km [22 miles]) and the same percentage of runners who had at least a college education (70%). Men constituted a slightly greater percentage of the nonparticipant group (87% compared with 83%). None of these differences was statistically significant.

Of the 966 runners who returned a baseline questionnaire and agreed to participate, 583 runners (60%) completed the study by returning more than 80% of the logs, including a log for the last month of the study. The response rate was 61% for men and 59% for women. Of those who finished the study, 485 (83%) were men and 98 (17%) were women. The 383 runners who dropped out during the year (that is, who stopped returning logs at some point) were similar to the study group in sex, age, average weekly distance, average weekly days of running, income, and perceived health. Furthermore, they did not drop out of the study because of injury. In another analysis,[20] it was shown that the injury rate among those who dropped out was the same as those who continued to return logs.

In the current study, male and female runners reported little difference in average weekly distance or days per week of running during the 3 months preceding the study. However, the women were younger than the men (36.1 years vs 41.6 years) and had fewer years of running experience (6.2 years vs 8.7 years) (Table 1).

During the 12-month observation period, 252 men (52%) and 48 women (49%) reported at least one running-related injury to the lower extremities that was severe enough to affect running habits, cause a visit to a health professional, or require the use of medication. When these initial injuries were categorized by severity, they were found to cause 29% of the injured men and 27% of the injured women to visit a health professional, whereas 21% of the injured men and 19% of the injured women reported the use of medication without a visit to a health professional. The remaining 50% of the injured men and 54% of the injured women reported that a reduction in running distance was the only consequence of the injury. The most frequent site of injury was the knee (24%) followed by the foot (22%). About 30% of all injuries reported had not occurred at that site before.

For men, age-adjusted univariate associations between lower-extremity injury and baseline risk factors indicated that the following factors were significantly ($P<.05$) associated with lower-extremity injury during the follow-up period: reporting a new lower-extremity injury during the previous 12 months, running regularly for less than 3 years, running 6 or 7 days per week, running in at least one marathon in the previous 12 months, and running an average of 32.0 km or more a week during the past 3 months (Table 2). Women had corresponding risk factors for running at least one marathon in the previous 12 months, running primarily on concrete (sidewalks), and running an average of 48.0 to 63.8 km per week.

We used a multiple logistic regression model to assess the combined effect of these risk factors on the occurrence of

Table 2.—Percentage in Each Category and Age-Adjusted Univariate Association of Each Variable With Lower-Extremity Injury

| Variable | Men (N=485) % | Men (N=485) OR | Men (N=485) 95% CI | Women (N=98) % | Women (N=98) OR | Women (N=98) 95% CI |
|---|---|---|---|---|---|---|
| Lower-extremity injury (past 12 mo) | 48 | 2.7 | 1.9-3.9 | 49 | 1.8 | 0.8-4.0 |
| Running experience, y | | | | | | |
| 0-2 | 9 | 2.6 | 1.3-5.0 | 15 | 1.8 | 0.6-5.9 |
| 3-9 | 61 | 1.0 | Reference | 68 | 1.0 | Reference |
| 10+ | 30 | 1.4 | 0.9-2.1 | 17 | 2.6 | 0.8-7.8 |
| Weekly distance for preceding 3 mo, km (miles) | | | | | | |
| 0-15.8 (0-9) | 14 | 1.0 | Reference | 19 | 1.0 | Reference |
| 16.0-31.8 (10-19) | 28 | 1.8 | 0.9-3.3 | 31 | 0.8 | 0.2-2.7 |
| 32.0-47.8 (20-29) | 26 | 2.0 | 1.1-3.8 | 23 | 1.4 | 0.4-5.2 |
| 48.0-63.8 (30-39) | 18 | 2.7 | 1.4-5.3 | 14 | 5.9 | 1.1-30.1 |
| 64.0+ (40+) | 14 | 5.0 | 2.4-10.6 | 13 | 2.1 | 0.5-9.5 |
| Run 6 or 7 d/wk | 26 | 2.2 | 1.4-3.4 | 30 | 1.7 | 0.7-4.0 |
| Marathon (during preceding 12 mo) | 18 | 2.0 | 1.2-3.2 | 13 | 4.0 | 1.0-15.5 |
| Hilly terrain | 34 | 1.1 | 0.7-1.6 | 34 | 1.0 | 0.4-2.5 |
| Concrete surface | 12 | 1.2 | 0.7-2.0 | 15 | 5.0 | 1.3-19.3 |
| Asphalt surface | 41 | 1.2 | 0.8-1.7 | 39 | 1.8 | 0.8-4.2 |
| Run in dark | 22 | 0.9 | 0.6-1.3 | 22 | 1.0 | 0.4-2.7 |
| Run in morning | 26 | 1.1 | 0.7-1.7 | 49 | 1.4 | 0.6-3.2 |
| Stretch before running | 54 | 1.1 | 0.8-1.5 | 44 | 1.6 | 0.7-3.5 |
| Body mass index | | | | | | |
| High (>74th percentile) | 24 | 0.7 | 0.4-1.0 | 24 | 2.3 | 0.8-6.3 |
| Reference (26th-74th percentile) | 51 | 1.0 | Reference | 51 | 1.0 | Reference |
| Low (<26th percentile) | 25 | 1.3 | 0.9-2.1 | 25 | 1.7 | 0.6-4.5 |

Table 3.—Logistic Regression Results for Combined Effect of Risk Factors on Injury Status

| Variable | Men (N=485) OR | Men (N=485) 95% CI | Women (N=98) OR | Women (N=98) 95% CI |
|---|---|---|---|---|
| Age, y | 1.0 | 1.0-1.0 | 1.0 | 0.9-1.0 |
| Lower-extremity injury (for preceding 12 mo) | 2.7 | 2.6-2.7 | 1.9 | 0.7-4.9 |
| Running experience, y | | | | |
| 0-2 | 2.2 | 1.5-3.3 | 1.4 | 0.3-6.4 |
| 10+ | 1.2 | 0.8-1.9 | 1.7 | 0.5-6.1 |
| Weekly distance for preceding 3 mo, km (miles) | | | | |
| 16.0-31.8 (10-19) | 1.6 | 0.8-3.0 | 2.1 | 0.5-9.7 |
| 32.0-47.8 (20-29) | 1.6 | 0.8-3.2 | 4.2 | 0.8-21.7 |
| 48.0-63.8 (30-39) | 1.7 | 0.8-3.6 | 7.4 | 0.9-60.3 |
| 64.0+ (40+) | 2.9 | 1.1-7.5 | 3.0 | 0.3-27.5 |
| Run 6 or 7 d/wk | 1.4 | 0.8-2.5 | 0.5 | 0.1-2.1 |
| Marathon (during preceding 12 mo) | 1.3 | 0.7-2.2 | 4.3 | 0.7-27.0 |
| Body mass index | | | | |
| High (>75th percentile) | 0.7 | 0.5-1.2 | 3.0 | 0.5-18.8 |
| Low (<26th percentile) | 1.2 | 0.7-1.9 | 2.0 | 0.6-6.6 |
| Concrete surface | 1.4 | 0.8-2.5 | 5.6 | 1.1-29.3 |
| Model $\chi^2$ | 65.55, 13 *df*, $P<.0001$ | | 24.11, 13 *df*, $P=.03$ | |

lower-extremity injuries during the follow-up period. For both men and women, the model included age, BMI, and the variables that were individually associated with lower-extremity injuries for either sex (Table 3).

For men, the full model was statistically significant ($P<.0001$) and had a $\chi^2$ of 65.55 ($df=13$). The strongest predictor of injury in the follow-up year was an initial report of running an average of 64 km (40 miles) or more per week at baseline (odds ratio[OR]=2.9). Other statistically significant risk factors were a lower-extremity injury in the previous year (OR=2.7) and running regularly for less than 3 years (OR=2.2).

For women, the full model was statistically significant ($P=.03$) and had a $\chi^2$ of 24.11 ($df=13$). The only statistically significant predictor of lower-extremity injury during the follow-up year was the practice of running more than two thirds of the time on concrete (OR=5.6). Although other factors had high ORs (weekly distance, marathon racing in the preceding year, and either high or low BMI), none was statistically significant.

## COMMENT

This study used a prospective design to examine the incidence of lower-extremity injury among a large group of habitual runners. During the 12-month follow-up, 52% of male and 49% of female runners reported at least one running-related injury to the lower extremities that was severe enough to cause these runners to reduce their running distance, consult with a health professional, or use medication. These results supported previously published studies that found that runners have annual rates of lower-extremity injury ranging from 24% to 65%.[6,7,11,18,14] Although these studies used different populations and different definitions of injury, the occurrence of high rates of problems is consistent throughout the studies.

For the men in this study, logistic modeling indicated that lower-extremity injuries could be best predicted by running

experience, recent previous injury, and weekly running distance. These risk factors are discussed below.

### Running Experience

The data suggested that both new runners and seasoned runners were at greater risk for injury than were the middle group, but the findings were statistically significant only for new runners. Marti et al[11] also reported an increased risk of injury for less experienced runners. In their group of runners, however, the lowest risk of injury was for the men who had been running the greatest number of years.

### Previous Injury

The odds of injury during the observation period for men who had suffered an injury due to any cause in the 12 months prior to the beginning of the study were nearly three times that of men who had not been injured previously. Several reports have identified previous injuries as a risk factor for subsequent injuries.[7,9,11]

### Running Distance

The distance run per week has consistently been associated with running injuries. Koplan et al,[6] Jacobs and Berson,[7] Marti et al,[11] and Blair et al[13] have all found that the risk of injury is directly associated with weekly distance. In a study of prison inmates, Pollock et al[8] found higher injury rates for groups of men who ran longer or more often than other runners in the study. Military studies[10] also have shown increasing injuries with increasing distance. In their study of Swedish runners, Lysholm and Wiklander[14] found that the distance covered in the preceding month was the best predictor of injury.

The men and women in this study experienced similar overall rates of injury (52% and 49%, respectively) but had no statistically significant risk factors in common in the adjusted analysis. One reason for this disparity may be the relatively small number of women in the study; with only 98 women, the power to detect an OR of 2.0 for a risk factor as common as an injury in the past 12 months (prevalence of 49%) is less than 50%. The risk factors that were statistically significant for men (weekly distance, previous injury, and inexperience) all had ORs greater than 1 for women (7.4, 1.9, and 1.4, respectively), but none was statistically significant. This correspondence suggests that certain risks may apply to both men and women, but our study lacked the power to confirm them. The only risk factor that achieved statistical significance in the adjusted logistic regression model for women (running on concrete) has not been previously reported. It may be unique to this study or to the South Carolina running environment.

In summary, data from this prospective study confirmed the previous findings that men and women have similar rates of injury[6,7,13] but do not yet clarify whether the risk factors for men and for women are the same. As in previous studies, age, BMI, hilly terrain, stretching, running in the dark, and running in the morning were not risk factors for running injuries among our participants.

In a recent analysis of the cost-effectiveness of exercise, Hatziandreu et al[21] point out that the cost of exercise as a means to reduce the incidence of coronary heart disease is appreciably less than the cost associated with other preventive or therapeutic interventions, even when the medical costs of exercise-related injuries are included. Nevertheless, the relatively high rate of injuries observed in this and other epidemiologic studies of running injuries is disconcerting, especially when one considers the appreciable pain, discomfort, worry, and medical costs associated with these injuries. Runners would welcome suggestions about methods to reduce their risk of injury. Pending further study of the possible risk role played by changes in running habits, the only identified risk factors from this and other studies are distance, previous injury, years of running experience, and, perhaps, running on sidewalks. Of the four, distance and running on sidewalks are the only two risk factors directly under the control of the runner. If we assume that the ORs from the logistic regression analysis for men would apply over a 2-year period, a man who would be willing to change his running distance from 64.0 km or more per week to 48.0 to 63.8 km per week would reduce his risk of injury by 15% in the first year. He could also expect a further reduction in injuries in subsequent years because his risk based on "previous injury" would consequently be reduced.

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