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ORIGINAL RESEARCH

WEEKLY RUNNING VOLUME AND RISK OF RUNNING-RELATED INJURIES AMONG MARATHON RUNNERS

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ABSTRACT

Purpose/Background: The purpose of this study was to investigate if the risk of injury declines with increasing weekly running volume before a marathon race.

Methods: The study was a retrospective cohort study on marathon finishers. Following a marathon, participants completed a web-based questionnaire. The outcome of interest was a self-reported running-related injury. The injury had to be severe enough to cause a reduction in distance, speed, duration or frequency of running for at least 14 days. Primary exposure was self-reported average weekly volume of running before the marathon categorized into below 30 km/week, 30 to 60 km/week, and above 60 km/week.

Results: A total of 68 of the 662 respondents sustained an injury. When adjusting for previous injury and previous marathons, the relative risk (RR) of suffering an injury rose by 2.02 [95% CI: 1.26; 3.24], $p < 0.01$, among runners with an average weekly training volume below 30 km/week compared with runners with an average weekly training volume of 30-60 km/week. No significant differences were found between runners exceeding 60 km/week and runners running 30-60 km/week (RR = 1.13 [0.5;2.8], p = 0.80).

Conclusions: Runners may be advised to run a minimum of 30 km/week before a marathon to reduce their risk of running-related injury.

Level of Evidence: 2b

Keywords: Running-related injury, marathon, risk factors, running volume.

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INTRODUCTION

An active lifestyle has several positive influences on physical fitness including reduction in the incidence of obesity, cardiovascular disease, and many other chronic health problems.[1,2] Because of its easy accessibility, running is a popular form of exercise all over the world.[2,3] Running a marathon has increased in popularity especially over the past 15-20 years.[4] According to the 2011 USA Marathon reports there has been an 80% increase in marathon finishers from 295,000 runners in 2001 to 525,000 in 2011. As the popularity of marathon running grows, more individuals may sustain a running-related injury (RRI) during or immediately after the completion of the marathon.[5] Results from previous studies of recreational and competitive runners reveal an incidence of injury during or after a marathon ranging between 16 and 92.4%.[3,6-13] Determining the risk factors for RRI among marathon runners is necessary for injury prevention. It is particularly important to identify modifiable risk factors since these factors are under the control of the runner.[14]

Weekly running volume is a modifiable risk factor possibly associated with injury development.[2] Macera et al and Walter et al found evidence in support of this in their studies: An absolute running volume greater than 64 km/week was a significant risk factor for male runners to sustain a RRI.[13,15] Based upon these findings, it has been suggested that injuries may be prevented by reducing weekly running volume.[16] The risk of injury is often calculated as an absolute injury risk during a specific amount of time. However, another approach is to calculate a relative risk of injury per kilometer or injury per hour of training.[17,18] Nielsen et al found that the risk of injury per 1000 hours of running declined with increasing running volume: Novice runners sustained 30 to 38 RRIs per 1000 hours of running while marathoners running more than 200 minutes per week sustained less than 10 RRIs per 1000 hours of running.[17] This finding was supported by Bovens et al who found that the number of injuries among persons preparing for a marathon race declined when the weekly volume rose from 15 kilometers per week to 37 kilometers per week.[12]

Marathon runners could, therefore, increase their weekly volume before the marathon in order to reduce their risk of injury. However, only one study was found that investigated the association between weekly running volume before a marathon race and the risk of sustaining an injury during or immediately after a marathon. In the study by Kretsch et al, marathoners were at greater risk of injury if they ran less than 60 kilometers per week.[10] Because of the paucity of knowledge within this area of research, it is necessary to conduct additional studies in order to determine the association between weekly running volume and injury. The purpose of the present study was to investigate whether the risk of injury varied among runners with different weekly running volume before a marathon race. The authors hypothesized that there would be a decline in the risk of running-related injury after a marathon among runners with a weekly running volume above 30 kilometers per week.

METHODS

Study design

The study was designed as a retrospective cohort study based on an online questionnaire. Because of its observational design, the study was not considered as a biomedical project according to Danish legislation and no approval from the local ethics committee was needed.

Setting and participants

Runners participating in the H. C. Andersen Marathon, Odense, Denmark (held on September 18, 2011) were considered for enrollment in the study. Inclusion criteria included completion of the marathon and the ability to read and write Danish. All participants provided informed consent.

Data collection

Data were collected in a post-race online questionnaire available for marathon participants immediately (1 hour after the race finished) upon their completion of the race. As many participants as possible were informed about the study at the finish line. Furthermore, flyers with description of the study and how to complete the online questionnaire were distributed among persons in the area of the finish line.

The runners were contacted by e-mail 9 days after the marathon and asked to complete the questionnaire.

A reminder mail was sent 19 days after the marathon. The e-mails to the runners contained information about the study and they included a link to the online questionnaire. The questionnaire was developed by the investigators and pilot-tested on marathon participants at three Danish marathons one year before the H. C Andersen Marathon. In the questionnaire, runners were asked to complete questions about demographic characteristics, previous injuries 12 months preceding the marathon, training volume before the marathon, running experience, and marathon experience. Questions were chosen based on known risk factors for running injuries.[2-5,8,18-20] The participants had to answer all the relevant questions to be able to submit the questionnaire. Access to the questionnaire was discontinued 37 days after the marathon. All completed questionnaires were received electronically. The submitted questionnaires were then screened and some were excluded for the following reasons: 1) Runners who did not complete the marathon, 2) Name and race time was not identical to the name and race time available via the official result page.

Outcome

The primary outcome of interest was running-related injuries that were reported after the marathon. The running-related injury definition was modified based on the injury definition used by Macera et al; a running-related injury was defined as an injury to muscles, tendons, joints and/or bones caused by running.[15] The injury had to be severe enough to cause or be expected to cause a reduction in distance, speed, duration, or frequency of running for at least 14 days. Conditions like muscle soreness, blisters, and muscle cramps were not considered as injuries, per the operational definition. After reading the injury definition in the questionnaire, participants were asked "Did you sustain any new injury after the H.C Andersen marathon that will affect your training ability for more than 14 days? Yes/no" If yes, the following question needed to be answered: "Location of the injury: Knee, foot and ankle, achilles tendon, lower leg, thigh / hamstring, hip, lower back or other".

Exposure

The primary risk factor of interest was average weekly kilometers of running before the marathon categorized into three groups: below 30 km/week, 30-60 km/week, and above 60 km/week. Other possible risk factors of interest were previous injury in the 12 months preceding the marathon, age, numbers of previous marathons, gender, body mass index (BMI), and the length of the longest run in the six weeks before the H.C Andersen Marathon.

Statistical analysis

Descriptive data for the demographic characteristics were presented as counts and percentage for dichotomous data, and as mean, standard deviation and 95% confidence interval for continuous data. All continuous data were normally distributed, as tested by histograms, and probability plots. Univariate binomial regression analysis was applied to investigate different risk factors for injury development. In the final model, multivariate binomial regression was used to analyze the average weekly volume and the development of injury adjusted for potential confounders. A priori selected confounders were: Previous injuries,[2-4,13,15,20,21] age,[2,8,21,22] previous marathons,[3,8,18,20,21] gender,[2,8] BMI,[2] and longest training distance in the six weeks before the marathon race. These a priori selected confounders were hypothesized to influence the association between weekly running volume and RRI. However, because of the low counts of several outcomes, data only allowed for adjustment for previous injury and previous marathons.[23] Differences were considered statistically significant at $p < .05$. All analyses were performed using STATA version 11.2 (Dallas, Texas, USA).

RESULTS

From the 2029 persons signed up for the marathon, a total of 680 questionnaires from runners participating in the marathon were gathered (return rate = 33.5%). Seventeen of the 680 runners did not complete the marathon and were therefore excluded. Furthermore, one participant was excluded because the name and race time was not on the official results page. A total of 662 runners were included in the study as presented in the flow chart (Figure 1).

The majority of the runners were males (80.2%); the average age was 41.4 ($\pm$10.4) years; and the average BMI was 23.0 kg/m^2 ($\pm$2.3). The demographic characteristics and training-related characteristics are presented in Table 1. Sixty-eight runners (10.3%) reported an injury after the marathon. The results

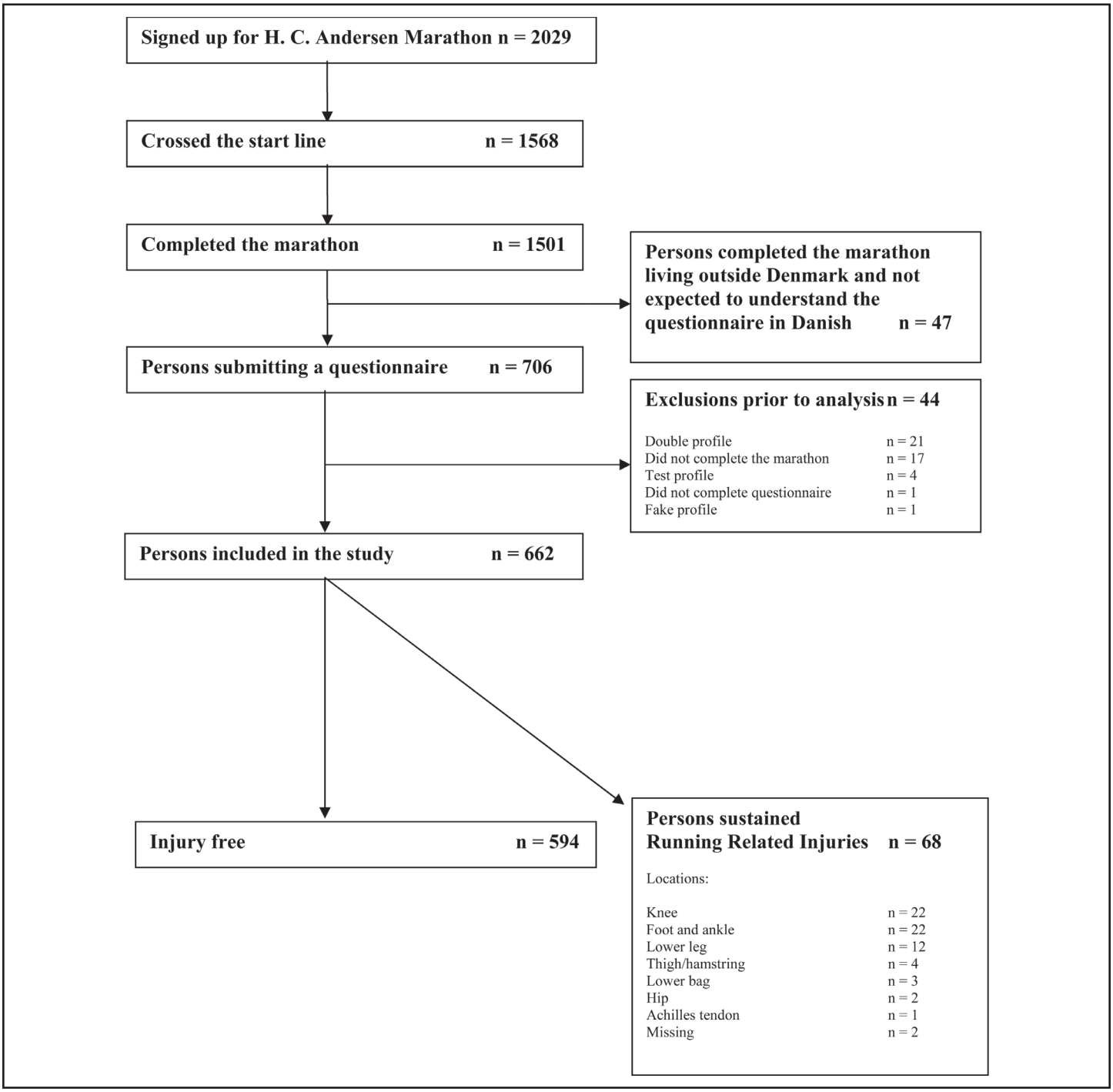

Figure 1. *H.C Andersen Marathon Flow Chart, demonstrating subject path for the current study.*

from the crude associations between different exposures of interest and the development of RRI are presented in Table 2.

The univariate analysis revealed that the relative risk of injury was significantly increased by 2.34 [1.47; 2.73] ($p < 0.01$) among runners with an average weekly training volume below 30 km/week as compared to runners with an average weekly training volume of 30-60 km/week. No significant association was found between persons running more than 60 km/week compared to runners with an average weekly training volume of 30-60 km/week. Development of RRI was found to be significantly dependent on age and previous injury: runners below 35 years of age were at increased risk of injury compared with

Table 1. *Characteristics of injured and healthy participants. SD = Standard Deviation. BMI = Body Mass Index, Kg = kilogram, m = meter, Km = kilometer.*

Variable	Unit	All n = 662	Injury free n = 594	Injured n = 68
Gender	Male / female	535 / 127	483 / 111	52 / 16
Age (mean ± SD)	Years	41.4 ± 10.4	42.0 ± 10.3	36.6 ± 10.0
BMI (mean ± SD)	Kg / m^2	23.0 ± 2.3	23.0 ± 2.3	23.1 ± 2.2
Previous injury (12 months prior to marathon)	Yes / no	273 / 389	231 / 363	42 / 26
Member of Running club	Yes / No	265 / 397	247 / 347	18 / 50
Running experience				
Above 5 years		351	320	31
2 – 5 years		262	233	29
Below 2 years		49	41	8
Previous marathons	Yes / No	478 / 184	441 / 151	37 / 31
Longest training distance 6 weeks prior to marathon				
Above 30 km		213	194	19
25-30 km		246	220	26
Below 25 km		203	180	23

older runners (relative risk (RR) = 2.31 [1.44; 3.73], $p < 0.01$). Previously injured runners faced an increased RRI risk (RR = 2.30 [1.45; 3.66], $p < 0.01$). The risk of RRI was significantly reduced among runners who had previously completed a marathon when compared with runners who participated in a marathon for the first time (RR = 0.46 [0.29; 0.72], $p < 0.01$). In contrast, the risk of suffering a RRI was not associated with gender, BMI, and longest training distance during the 6 weeks preceding the marathon. Table 3 presents the results of the analysis of the association between average weekly training volume and the development of RRI adjusted for a priori selected confounders.

When adjusting for previous injury and previous marathons, an increased risk of 2.02 [1.26; 3.24], $p < 0.01$, was found among runners with an average weekly training volume below 30 km/week when compared with runners with an average weekly training volume of 30-60 km/week. The group of runners running more than 60 km/week also had an increased risk of RRI compared with the reference group (RR = 1.13 [0.5; 2.8], p = 0.80). However, this association was not statistically significant. The counts and percentages of the injuries, by location, are presented in Table 4. The knee, foot, and ankle were the most common locations affected by injuries.

DISCUSSION

The findings of the present study of the association between weekly running volume and the risk of RRI after completion of a marathon race revealed that the risk of injury was significantly increased to 134% among runners with an average weekly training volume below 30 km/week as compared to runners with an average weekly training volume of 30-60 km/week. When adjusting for previous injury and previous marathon participation, the increased risk among runners with an average weekly training volume below 30 km/week declined to 102%, and the association remained significant. Based on this, it appears that runners training for a marathon should run more than 30 km/week during training before a marathon in order to reduce their risk of injury. Interestingly, the threshold of 30 km/week is lower than the threshold suggested by Kretsch et al who found that marathon entrants needed to average at least 60 km/week in the last two to three months before the race to minimize the risk of requiring treatment on the day of the race.[10] In the present study, no decreased

Table 2. *Crude estimates on different exposures of interest with development of RRI. P values represent estimates on the difference between healthy and injured participants. BMI = Body Mass Index (kilogram/meter^2), RR = relative risk, SD = Standard Deviation, 95% CI = 95% confidence interval, [a] = Binomial regression test used, [b] = Chi^2 test used with relative risk as measure of association.*

Stratum	RR	95% CI	*p*
Average weekly training volume			
Above 60 km/week	1.00	[0.40; 2.50]	$p = 0.99$
30-60 km/week (reference)	1[a]		
0-30 km/week	2.34	[1.47; 3.73]	$p < 0.01$
Previous Injury (yes versus no)	2.30[b]	[1.45; 3.66]	$p < 0.01$
Previous marathons (yes versus no)	0.46[b]	[0.29; 0.72]	$p < 0.01$
BMI (> 25 vs ≤ 25)	0.88[b]	[0.47; 1.68]	$p = 0.70$
Longest training distance 6 weeks prior to marathon			
Above 30 km (reference)	1[a]		
25 – 30 km	1.18	[0.68; 2.08]	$p = 0.55$
Below 25	1.27	[0.71; 2.26]	$p = 0.42$
Gender (women versus men)	0.77[b]	[0.46; 1.31]	$p = 0.34$
Age			
Below 35 years	2.31	[1.44; 3.73]	$p < 0.01$
35 – 50 years	1[a]		
Above 50 years	0.82	[0.38; 1.75]	$p = 0.60$

risk of injury was found among runners exceeding 60 km/week during training before a marathon compared with runners running 30–60 km/week. In two previous studies that examined marathon runners, Middelkoop et al and Wen et al reported that an increasing running volume per week (average from preceding 3-months total) was protective for RRI.[3,5] Conclusively, there seems to be little evidence for

Table 3. *Results from the multivariate binomial regression analysis on the association between average weekly training volume and development of running related injuries adjusted for the effect of previous injury and previous marathon participation. RR = relative risk, 95% CI = 95 percent confidence interval.*

Stratum	RR	Standard error	95% CI	*p*
Average weekly training volume				
Above 60 km/week	1.13	0.52	[0.45 ; 2.79]	$p = 0.80$
30-60 km/week (reference)	1			
0-30 km/week	2.02	0.49	[1.26; 3.24]	$p < 0.01$
Previous Injury (yes vs no)	2.23	0.52	[1.41; 3.52]	$p < 0.01$
Previous marathon (yes vs no)	0.60	0.14	[0.37; 0.95]	$p = 0.03$

Table 4. *The injury locations of the 68 runners sustaining injuries presented as counts and percentage.*

Injury location	Count	Percentage
Knee	22	32.4
Foot and Ankle	22	32.4
Lower Leg	12	17.6
Thigh / hamstring	4	5.9
Lower back	3	4.4
Hip	2	2.9
Achilles tendon	1	1.5
Missing	2	2.9

setting an upper weekly 60-km running volume threshold in order to reduce the risk of injury among marathon runners. The results from the present study and the results from the studies by Middelkoop et al and Wen et al, are in contrast to the results of studies on habitual runners and runners participating in 6-22 km running events reported by Macera et al and Walter et al: a weekly running volume above 64 km/week was associated with injury development.[13,15] An upper training limit of 60 km/week among habitual runners may exist, however, the relationship between weekly running distance and the risk of RRI is multifaceted and complex and it is possible that there is a fine balance between overuse and under-conditioning.[8] Based on this, it is important to address whether it is reasonable to conclude that injuries among all runners, regardless their running experience, are prevented by not exceeding a weekly volume of 60 kilometers as suggested by Fields et al.[16] Based on the results of the present study, the authors suggest that a lower rather than an upper threshold for a minimal weekly volume per week should be considered when runners are scheduling their training before a marathon race.

Other risk factors for injury found in this study were previous injury ($p < 0.01$), younger age ($p < 0.01$), and lack of previous marathon participation ($p < 0.01$); however, no associations were found for gender, BMI, and longest training distance during the six weeks preceding the marathon. Many studies support the theory that previous injury is a risk factor for RRI.[2-4,13,15,20,24,25] The findings of the present study support the assumption that previously injured individuals are more likely than others to sustain new injuries. Possible mechanisms that may lead to occurrence of new injury are incomplete recovery or rehabilitation from a previous injury and the ongoing presence of the predisposing factors that caused the previous injury.

Lower age was a risk factor for RRI in this study. This is supported by Kretsch et al, but rejected by Nicholl et al, Satterthwaite et al and Wen et al who reported that higher age was a significant risk factor for injury development.[8-10,21] In contrast, van Middelkoop et al, van Mechelen et al, and Walter et al reported no association between age and injury development.[3,13,24] Finally, Satterthwaite et al suggested an inverted U-shaped relation between age and RRI and that injury is less likely to occur in the

younger and older respondents possibly because it is only well conditioned young athletes who choose to attempt marathons.[8] The inverted U-shaped relationship was not confirmed in the present study. An explanation of the conflicting results on age and injury development may be running experience. It may be likely, that running experience is a confounder on the association between age and risk of injury. Experienced runners with more than one previous marathon were found to be at a decreased risk of RRI. This result is supported by other studies.[4,8,20,26] If experienced runners are hypothesized to be older than novice runners, they may have developed musculoskeletal adaptation to running and they are therefore less predisposed to injuries. Additionally, they may be better able to interpret their body's signals and hence train more appropriately before RRIs occur. Future studies should investigate age as a predictor of injury and they should control for running experience.

No association between gender and RRI was found in present study. This finding is supported in a review by Mechelen et al. that included 65 studies.[24] Men and women seem to be at the same risk of injury, but the diagnoses vary across gender. In a study by Satterthwaite et al. on marathon runners, men were at higher risk of hamstring and calf problems than women, whereas women were at higher risk of hip injuries than men.[8]

Studies investigating BMI as a risk factor for RRI have reported conflicting results. Like the present study, some studies find no association between BMI and RRI.[13,15] Other studies find that a low BMI is a risk factor,[19,21] whereas and others find that a high BMI is a risk factor.[5,27] The range of BMI among the participants of the present study may have been too narrow to find an association, but the authors speculate that BMI as a risk factor for RRI may have a U-shaped curve. This assumption is supported by the findings of Marti et al who find that both extremes of BMI are risk factors for RRI.[25]

The authors of the current study found no association between RRI and the distance of the longest run in the six weeks before the marathon; and no other studies were found that investigated this possible risk factor. Although an association was expected, a larger sample size and a categorization of participants into more discrete distance categories may be needed to identify and describe such a relationship.

A total of 10.3% of the participants suffered a new injury after the H.C. Andersen Marathon. This is a lower rate than quoted in other studies which report incidences of new injuries of 16-92.4%.[3,6-13,2,3,7-13] The large incidence range of RRIs during or immediately after a marathon may be due to variations in the study designs. Many of the published studies on runners and RRI lack a standard definition of injury. In some studies, running injuries were defined as running-related injuries to the lower extremities,[19,28] while other studies also included non-lower-extremity injuries and more general problems such as headache, dehydration, fatigue, blisters, muscle cramps, and others.[8,10,18,22] Furthermore, the type of runners selected for each study varied. Usually a specific selection of runners was made such as male runners, recreational runners, and runners in a charity marathon. All these different factors complicate and limit comparisons between study results. The present study used an injury definition proposed by Macera et al, and the included injuries that occurred after the marathon.[15] With this injury definition, the authors only analyzed injuries affecting the runners for at least 14 days and excluded recurrent injuries. This may explain lower incidence of RRI when compared with other studies. In the present study, the most common sites affected by running-related injuries were the knee and foot/ankle. In other studies on marathon runners, the knee was also found to be the location predominantly affected by injuries, followed by the foot.[7,13,15,29,30]

The present study has several limitations: First, the incidence of the injuries was obtained retrospectively via a self-reported questionnaire. Self-reporting may impact accuracy and introduce recall or reporting bias. The authors attempted to minimize recall bias by setting the deadline for answering the questionnaires at 37 days after the marathon. However, in the ideal scenario, a prospective study would reduce the amount of recall bias, especially if training volume was quantified objectively by GPS or accelerometry.[17] A second limitation was the lack of adjustment for potential confounders. We strictly followed the rules of statistical analysis in the sense that no more than a single parameter was chosen for

every 15 injuries in the adjusted analysis. However, the consequence of this stringency was that possible confounders were excluded from the multivariate analysis of the association between weekly volume and the development of injury. A third limitation was the response rate of 33.5%, while comparable to the response rate reported in some studies,[21,31] is lower than the rates reported in other studies.[3,8,20,32]

The percentage of participants who had signed up for the marathon but did not complete for some reason was 26.0%. Some of these participants may have been injured before the marathon and some may have been injured during the marathon. It was not possible to contact these persons at the finish line. For this reason, it is possible that fewer chose to participate compared with persons who completed the marathon. Selection bias may therefore exist between runners completing the questionnaire and runners who did not. This would underestimate our RRI incidence. On the other hand, participants who sustained an RRI may have been more willing to participate, in which case the RRI incidence could have been overestimated.

Despite these limitations, the results of this study may contribute to the growing body of knowledge that describes the need for examining a lower threshold for weekly training volume in future studies rather than solely addressing an upper threshold, which is currently considered the main preventive strategy for reducing the risk of injury among runners. A study with more participants would allow a statistical analysis with smaller intervals of km/week which is required in order to expand on the knowledge within this area of research. The authors of the current study recommend that a specific injury definition and a prospective design with objective measures of training volume should be used in future studies. In addition, for ease of comparison across studies, future studies should use the same method to calculate the injury rate: either injury per amount of time, injury per kilometer, or injury per hour of training.

CONCLUSION

Runners with a weekly training volume above 30 km/week before a marathon race had lower risk of injury after completion of a marathon as compared to runners with a weekly training volume below 30 km/week. Runners may be advised to run a minimum of 30 km/week before a marathon in order to reduce their risk of RRI.

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