A commentary by Lars Engebretsen MD, PhD, is linked to the online version of this article at jbjs.org.

Low Prevalence of Hip and Knee Arthritis in Active Marathon Runners

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Background: Existing evidence on whether marathon running contributes to hip and knee arthritis is inconclusive. Our aim was to describe hip and knee health in active marathon runners, including the prevalence of pain, arthritis, and arthroplasty, and associated risk factors.

Methods: A hip and knee health survey was distributed internationally to marathon runners. Active marathoners who completed ≥5 marathons and were currently running a minimum of 10 miles per week were included (n = 675). Questions assessed pain, personal and family history of arthritis, surgical history, running volume, personal record time, and current running status. Multivariable analyses identified risk factors for pain and arthritis. Arthritis prevalence in U.S. marathoners was compared with National Center for Health Statistics prevalence estimates for a matched group of the U.S. population.

Results: Marathoners (n = 675) with a mean age of 48 years (range, 18 to 79 years) ran a mean distance of 36 miles weekly (range, 10 to 150 miles weekly) over a mean time of 19 years (range, 3 to 60 years) and completed a mean of 76 marathons (range, 5 to 1,016 marathons). Hip or knee pain was reported by 47%, and arthritis was reported by 8.9% of marathoners. Arthritis prevalence was 8.8% for the subgroup of U.S. marathoners, significantly lower ($p < 0.001$) than the prevalence in the matched U.S. population (17.9%) and in subgroups stratified by age, sex, body mass index (BMI), and physical activity level ($p < 0.001$). Seven marathoners continued to run following hip or knee arthroplasty. Age and family and surgical history were independent risk factors for arthritis. There was no significant risk associated with running duration, intensity, mileage, or the number of marathons completed ($p > 0.05$).

Conclusions: Age, family history, and surgical history independently predicted an increased risk for hip and knee arthritis in active marathoners, although there was no correlation with running history. In our cohort, the arthritis rate of active marathoners was below that of the general U.S. population. Longitudinal follow-up is needed to determine the effects of marathon running on developing future hip and knee arthritis.

Level of Evidence: Prognostic Level III. See Instructions for Authors for a complete description of levels of evidence.

Although distance running is associated with numerous health benefits, the impact on hip and knee joint health is inconclusive. Distance running has been associated with an increased prevalence of arthritis in some studies[1-4], but other studies have shown an inverse association or no association[5-11]. Arthritis is the most common cause of physical disability in adults in the United States[12]. By 2040, the number of adults with arthritis has been projected to reach 78.4 million, or 26% of the adult population[12-14]. Although the cause of arthritis is not fully understood and multifactorial, arthritis is associated with age, family history, female sex, race, obesity, limb alignment, muscle weakness, and trauma[12].

Biomechanically, it seems intuitive that repetitive load-bearing cycles of running, long-term, over long distances, may be detrimental to the hip and knee. Joint load forces while running

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are approximately 8 times body weight at the knee and 5 times body weight at the hip[15,16]. A proposed explanation as to why runners do not have high arthritis rates includes a relatively short duration of ground contact and long stride lengths that blunt the high peak joint loads, such that per-unit distance loads are equivalent to walking[15]. Additionally, running-enhanced limb compliance, muscle mass, bone density, and body weight maintenance may counter forces through the joints[2]. One study showed a 2.7% arthritis rate in runners, as well as reduced risk related to lower body mass index (BMI)[17].

The relationship between distance running and hip and knee arthritis is unclear. Prior studies have been centered on radiographs, small cohorts, and heterogeneous athletic populations[2-7]. Our large, cross-sectional study aims to describe hip and knee health in active marathon runners, including the prevalence of pain, arthritis, and arthroplasty, and associated risk factors. Also, we compare arthritis prevalence in U.S. marathoners to prevalence estimates for a matched U.S. adult population.

Materials and Methods

Through an electronic survey distributed internationally to marathon clubs, 953 marathon runners provided information with regard to their hip and knee health and running history. The international scope enabled inclusion of a large number of high-volume, high-intensity marathoners over a range of demographic characteristics, with the hypothesis that running volume and intensity would relate to increased rates of pain and arthritis of the hip and knee. Responses were collected between December 2015 and March 2016. Participation was on a voluntary basis, and participants were informed that their responses would be used in a scientific publication.

Target subjects were restricted to adult active marathoners (≥18 years of age) to avoid survival bias associated with an unknown magnitude of runners who retire early because of arthritis and did not participate in the survey. Of the 953 respondents, 19 (2%) reported that they were no longer running and were excluded. Knee pain was the most common reason (42%). Other reasons included a change in fitness goals (26%), hip and knee pain (11%), total hip arthroplasty (11%), hip pain (5%), and muscle imbalance (5%). Inclusion criteria required completion of ≥5 marathons and active running status covering a minimum of 10 miles per week, which identified 675 marathon runners for further analysis.

Active marathoners originated from 31 countries: United States (430), United Kingdom (50), Denmark (37), Canada (20), Australia (20), the Netherlands (18), Ireland (15), New Zealand (14), Germany (11), Finland (9), Belgium (7), Sweden (7), India (5), France (4), South Africa (3), Mexico (3), Malaysia (3), the Philippines (3), Singapore (3), Italy (2), Hong Kong (1), Hungary (1), Norway (1), Trinidad & Tobago (1), Austria (1), Belarus (1), Brazil (1), Iran (1), Japan (1), Korea (1), and Russia (1).

Nineteen survey questions (see Appendix) were designed to assess running history and hip and knee health. Demographic information included age, sex, height, weight, and country of origin. Running history included running duration (years), weekly mileage, number of marathons completed, personal record time (an indicator of running intensity), and current running status. Joint health questions inquired about hip or knee pain in the past year, doctor-diagnosed hip or knee arthritis, age of diagnosis, family history of arthritis (arthritis in a parent or sibling), and hip or knee surgical history. The question pertaining to arthritis read as follows: "Have you ever been diagnosed by a doctor with hip or knee arthritis (worn-out cartilage)?" The formulation of this question was based on epidemiological studies, including the National Health Interview Survey (NHIS) conducted by the U.S. National Center for Health Statistics (NCHS), Centers for Disease Control and Prevention (CDC), which was used in our study as a reference for arthritis prevalence in the U.S. population[12,18,19]. The NHIS is a health survey administered to adult U.S. citizens that serves as the principal source of information on the health of the civilian household population of the United States[18]. The NHIS survey question pertaining to arthritis read as follows[18,19]: "Have

TABLE I Demographic Characteristics of Marathon Runners in the Study

Demographic Characteristics	All Marathoners (N = 675)	U.S. Marathoners (N = 430)
Age* *(yr)*	47.9 ± 11.6 (18 to 79)	46.1 ± 11.7 (18 to 74)
Sex†		
Male	392 (58.1%)	209 (48.6%)
Female	283 (41.9%)	221 (51.4%)
BMI* *(kg/m²)*	23.6 ± 3.4 (16.1 to 47.8)	23.6 ± 3.5 (17.1 to 47.8)
No. of marathons*	75.5 ± 116.6 (5 to 1,016)	48.2 ± 89.2 (5 to 1,016)
Duration of running* *(yr)*	18.8 ± 12.4 (3 to 60)	19.0 ± 12.2 (3 to 55)
Mileage* *(miles/week)*	36.4 ± 17.0 (10 to 150)	34.7 ± 16.2 (10 to 150)

*The values are given as the mean and the standard deviation, with the range in parentheses. †The values are given as the number of runners, with the percentage in parentheses.

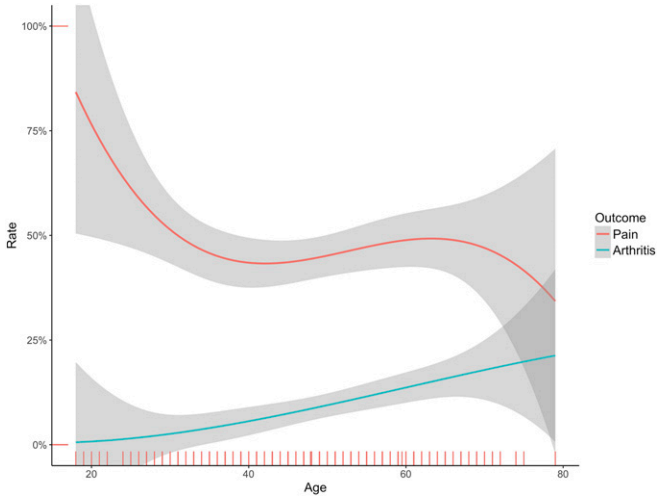


Fig. 1

Graph showing the rates of pain and arthritis across age in marathoners. The shaded regions indicate the 95% CI.

you ever been told by a doctor or other health professional that you have some form of arthritis?"

Arthritis prevalence in U.S. marathoners was compared with prevalence estimates for the U.S. population overall and was stratified by selected characteristics (age, sex, BMI, and physical activity level) based on the 2010 to 2012 NHIS[12,17]. Coarsened exact matching was employed to match the U.S. population to the U.S. marathoner subset by age, sex, and BMI[20]. Physical activity level within the U.S. population was reported by frequency and duration of moderate or vigorous activity. Americans were categorized as inactive (0 minutes per week), insufficient (1 to 149 minutes per week), and sufficient (≥150 minutes per week) according to the U.S. Department of Health and Human Services 2008 Physical Activity Guidelines[21].

Statistical Analysis

Univariate and multivariable regression analyses were performed to identify risk factors for hip and knee pain and arthritis in marathoners. Multivariable analysis results are reported as odds ratios (ORs) with 95% confidence intervals (CIs). Significance was defined by $p < 0.05$. All analyses were performed using R 3.1.1 (R Foundation for Statistical Computing), utilizing the "rms" package to perform the logistic regression.

Results

The mean age of marathoners was 47.9 years (range, 18 to 79 years), and 41.9% of runners were female. Marathoners ran a mean distance of 36.4 miles per week (range, 10 to 150 miles per week) over a mean time of 18.8 years (range, 3 to 60 years) and completed a mean number of 75.5 marathons (range, 5 to 1,016 marathons). Table I summarizes the demographic characteristics.

Hip and/or knee pain was reported by 317 marathoners (47.0%), consisting of 22.2% with knee pain, 11.1% with hip pain, and 13.6% with hip and knee pain; 35.4% reported a positive family history of arthritis. The rate of arthritis in marathoners was 8.9% (60 of 675), involving the knee (5.8%), hip (2.1%), and hip and knee (1.0%). Figure 1 depicts rates of pain and arthritis across age. Of marathoners with arthritis, the mean age at the time of diagnosis was 46.8 years (range, 18 to 68 years). Of marathoners who were ≥65 years of age, the arthritis rate was 24.5%.

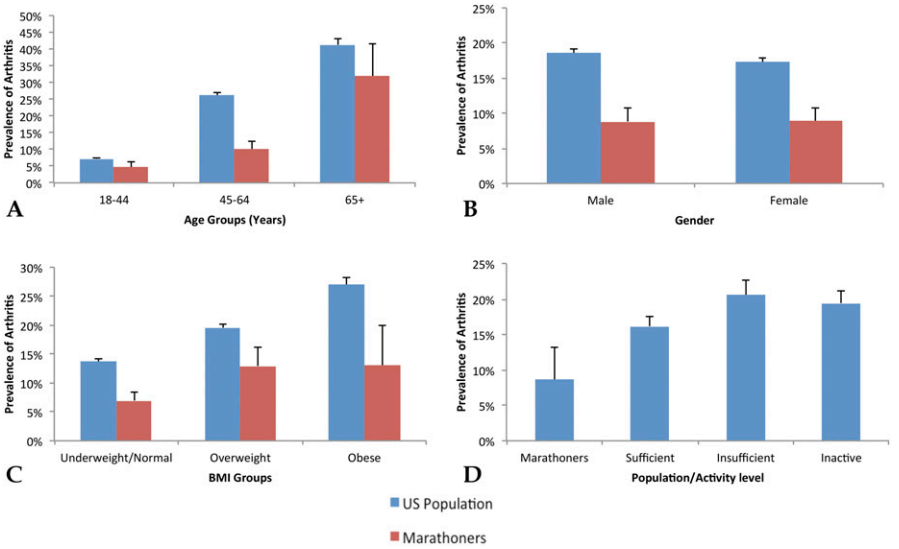


Fig. 2

Bar graphs showing that arthritis prevalence in U.S. marathoners is significantly lower than the prevalence in a matched U.S. adult population (National Health Interview Survey 2010 to 2012), both overall and when stratified by selected demographic characteristics of age ($p < 0.0001$) (**Fig. 2-A**), sex ($p < 0.0001$) (**Fig. 2-B**), BMI ($p < 0.0001$) (**Fig. 2-C**), and physical activity level ($p < 0.0001$) (**Fig. 2-D**). The error bars indicate the 95% CI.

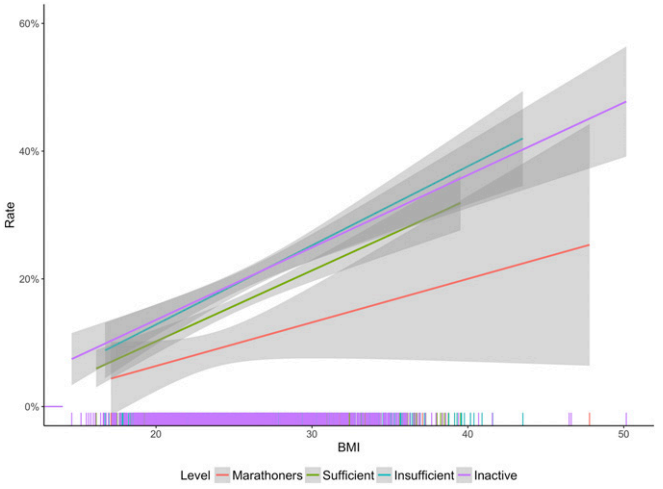


Fig. 3-A

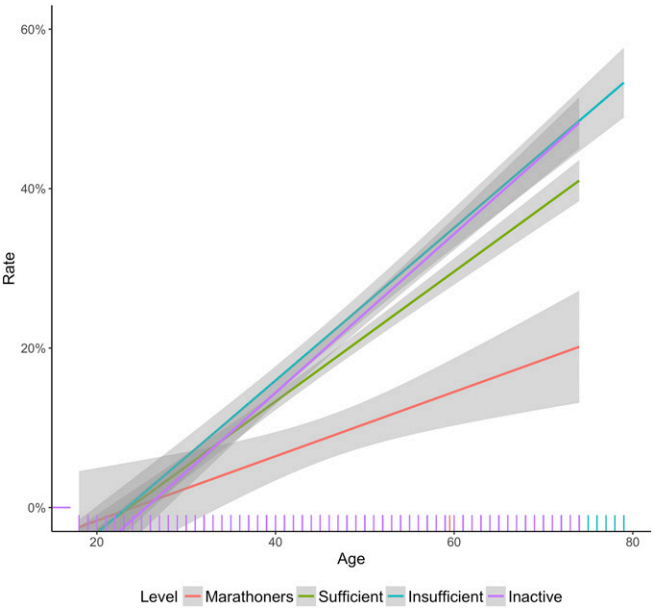


Fig. 3-B

Graphs showing the prevalence of arthritis in U.S. marathoners compared with the prevalence in a matched U.S. adult population (National Health Interview Survey 2010 to 2012), stratified by physical activity level (inactive, insufficient, and sufficient activity levels) in relation to BMI ($p < 0.0001$) (**Fig. 3-A**) and age ($p < 0.0001$) (**Fig. 3-B**). Despite increased arthritis rates with age and BMI, there is an inverse relationship between activity level and arthritis rate. The shaded regions indicate the 95% CI.

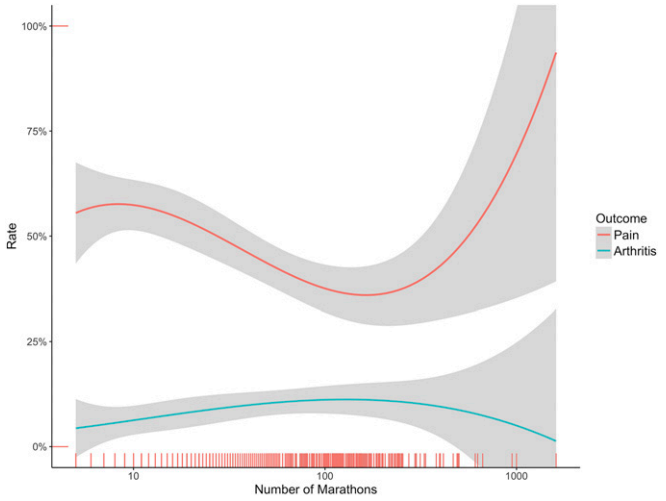
Arthritis prevalence in U.S. marathoners (n = 430) was compared with prevalence estimates for a matched group of the U.S. adult population (n = 9,526). Similar to the U.S. population, the subset of U.S. marathoners showed increased arthritis prevalence in female individuals and among those who were overweight or obese. Arthritis prevalence in U.S. marathoners (8.8%) was significantly lower ($p < 0.001$) than the prevalence in the matched U.S. population (17.9%); it was also significantly lower ($p < 0.001$) than the prevalence in subgroups stratified by age, sex, BMI, and physical activity level (Fig. 2). Despite an increasing arthritis rate with BMI and age (Fig. 3), the higher level of physical activity in marathoners was related to diminished arthritis rates ($p < 0.001$). Although arthritis rates for U.S. and international marathoners were comparable, we avoided direct comparison between the international marathoners and the U.S. population because of confounding variables of diet, attitude, and cultural differences.

Multivariable analysis (Table II) identified history of hip or knee surgical procedures as most predictive of hip and knee pain. Hip and knee pain correlated with arthritis (OR, 8.56 [95% CI, 3.95 to 21.23]; $p < 0.001$). An increasing number of marathons was associated with decreased rates of joint pain (OR, 0.57 [95% CI, 0.40 to 0.82]; $p = 0.002$) (Fig. 4). There was a slight upward trend in arthritis rate as the number of marathons increased (Fig. 4), which was not a significant predictor of arthritis in the multivariable model (OR, 1.22 [95% CI, 0.64 to 2.33]; $p = 0.55$). An increasing number of marathons correlated with an upward trend in age, as older adults tended to run more marathons. Multivariable analysis identified risk

TABLE II Multivariable Analysis of Risk Factors for Pain and Arthritis of the Hip and Knee in Marathon Runners

Risk Factor	OR*	P Value
Age, per year		
Pain	1.01 (0.99 to 1.03)	0.185
Arthritis	1.05 (1.02 to 1.08)	<0.001
BMI, per kg/m^2		
Pain	1.00 (0.96 to 1.05)	0.867
Arthritis	1.07 (0.99 to 1.16)	0.090
Female sex		
Pain	1.39 (0.98 to 1.97)	0.063
Arthritis	1.61 (0.85 to 3.06)	0.144
Family history		
Pain	1.23 (0.89 to 1.71)	0.209
Arthritis	2.52 (1.41 to 4.47)	0.002
History of hip or knee surgery		
Pain	2.56 (1.58 to 4.17)	<0.001
Arthritis	5.43 (2.94 to 10.03)	<0.001
No. of marathons (log_{10})		
Pain	0.57 (0.40 to 0.82)	0.002
Arthritis	1.22 (0.64 to 2.33)	0.551

*The values are given as the OR, with the 95% CI in parentheses.



No. of Marathons	5-10	11-20	21-50	51-100	>100
N	128	105	139	128	175
Mean Age	39	43	48	52	54

Fig. 4

Graph showing the rate of hip and knee pain and arthritis with increasing number of marathons. An increasing number of marathons was associated with decreased rates of joint pain (OR, 0.57 [95% CI, 0.42 to 0.78]; p = 0.002). The number of marathons was not a significant predictor of arthritis (OR, 1.22 [95% CI, 0.64 to 2.33]; p = 0.551). The shaded regions indicate the 95% CI.

factors for arthritis in marathoners, including increasing age (OR, 1.05 [95% CI, 1.02 to 1.08] per year; p = 0.002) and runners with a family history of arthritis (OR, 2.52 [95% CI, 1.41 to 4.47]; p = 0.002) or a history of hip or knee surgical procedures (OR, 5.43 [95% CI, 2.94 to 10.03]; p < 0.001). There was no positive relationship between pain or arthritis and running duration, intensity, weekly mileage, or number of marathons.

A history of hip or knee surgical procedures, present in 12.6%, was the most pronounced risk factor for pain and arthritis. In marathoners with a history of surgical procedures, 42.7% reported pain in the operative joint, 67.4% reported generalized hip and/or knee pain, and 28.1% reported arthritis, predominantly involving the knee (76% of those with arthritis). Prior surgical procedures included meniscal surgical procedures (34.8% of prior surgical procedures), knee arthroscopy (33.7%), anterior cruciate ligament (ACL) reconstruction (19.1%), and hip arthroscopy (3.4%). Other procedures included distal femoral tumor excision, hip cyst curettage and bone-grafting, open reduction and internal fixation of slipped capital femoral epiphysis, hip fracture open reduction and internal fixation, periacetabular osteotomy, pes anserine bursectomy, multiligament knee reconstruction, and microfracture of a knee chondral defect. Six of the analyzed marathoners underwent arthroplasty, including 1 who underwent total knee arthroplasty, 1 who underwent bilateral total knee arthroplasty, 1 who underwent hip resurfacing arthroplasty, and 3 who underwent total hip arthroplasty. Among retired marathoners who were excluded from analysis, there were 2 additional cases of total hip arthroplasty, and these marathoners discontinued running after the surgical procedure because of postoperative limb-length discrepancy and surgeon recommendation. There was 1 individual running after a unicondylar knee arthroplasty who was excluded from analysis for not meeting the running volume inclusion criteria.

Discussion

Among active marathoners, we found no correlation between running history and arthritis. Age, family history, and surgical history were independent predictors for hip and knee arthritis in marathoners. However, in the United States, our cohort of marathoners demonstrated an arthritis rate below that of the general population, both overall and across subgroups stratified by age, sex, BMI, and physical activity level.

Although we found no association between running history and arthritis in marathoners, other studies have linked distance running with increased arthritis prevalence[1-4]. Cheng et al. found that running 20 miles per week was associated with self-reported arthritis among men <50 years of age[1]. Increased prevalence of radiographic hip and knee arthritis was shown in small cohorts of former elite distance runners and tennis players[3]. Tveit et al. demonstrated increased prevalence of arthritis and arthroplasty in former male elite athletes, driven by the inclusion of contact athletes and athletes with a history of knee injury[2]. These studies were largely centered on radiographs, small cohorts, and heterogeneous athletic populations. Alternatively, several studies have documented similar rates of radiographic, clinical, or symptomatic arthritis between runners and nonrunners[5-11]. Williams reported a 2.7% arthritis rate in runners[17]. Sohn and Micheli showed that distance running was not associated with arthritis in former college cross-country runners compared with former college swimmers over 25 years of follow-up[8].

Several factors may counter the effect of mechanical loading of the joints while running. The relatively short duration of ground contact and long stride lengths during running blunt the effect of high joint loads, such that the per-unit distance loads are equivalent between running and walking[15]. Lane et al. found 40% more bone mineral content in runners compared with controls and no differences in radiographic, clinical, or symptomatic arthritis[7]. Hyldahl et al. showed a running-induced decrease in knee synovial fluid pro-inflammatory cytokine concentration in healthy young adults after 30 minutes of running, suggesting an anti-inflammatory chondroprotective effect[22]. Several studies have indicated an inverse relationship between muscle mass and arthritis and suggest that muscle fatigue, diminished proprioception, and age-related decreased tissue compliance, as well as joint injury, disease, or surgical procedure, may contribute to arthritis[2,23-26]. Our findings align with this theory as aging, insufficient physical activity, and joint

surgical procedures correlated with arthritis. We also showed an inverse relationship between arthritis and physical activity level, and arthritis rates were further reduced in marathoners, supporting joint health benefits from physical activity.

A prior joint surgical procedure was the strongest predictor of pain and arthritis in marathoners. Disruption of the cruciates, tibiofemoral osteochondral surface, or menisci leads to changes in the path of the instantaneous center of the knee and may result in arthritis. For example, several studies have indicated that ACL reconstruction does not restore normal kinematics during dynamic, functional loading, and graft degradation may occur over time[27,28]. An increased risk of arthritis has been found after ACL reconstruction, which may be related to abnormal kinematics associated with ACL injury and reconstruction[28-30]. In a previously compromised joint, our current study suggests a relationship between high-impact running cycles and arthritis. Teichtahl et al. found that preexisting joint health determines the response to persistent vigorous physical activity over time[9]. Among older adults with clinically healthy knees followed longitudinally, participation in regular vigorous physical activity was associated with deleterious knee cartilage changes only in those with preexisting changes on magnetic resonance imaging (MRI)[9]. Runners with joint injury or those who had undergone surgical procedures after joint injury may decide to vary their exercise practices to include lower-impact activities. Research should examine the biomechanics and long-term outcomes of athletes following joint injury and surgical procedures.

Surprisingly, an increased number of marathons was associated with decreased joint pain. Although this may reflect benefits associated with distance running, it may also reflect self-selection whereby runners with pain discontinue running. Tesarz et al. found that athletes possessed higher pain tolerance compared with normally active controls, possibly related to genetics or conditioning[31]. Bruce et al. found that although musculoskeletal pain increases with age, there was no increase in pain in older adults who participated in regular vigorous exercise[32]. There was 25% less pain and less arthritis in runners compared with those who had never been runners[32]. Chakravarty et al. found significantly divergent physical disability levels later in life favoring runners compared with non-runners over a 21-year longitudinal study[33]. Even among aging adults with mild to moderate knee arthritis, regular exercise reduced pain, whereas inactivity was associated with greater pain[32,34]. Poor physical function and weak thigh extensor strength were linked to frequent pain in older adults with bilateral knee osteoarthritis[35]. The current study and the U.S. population data support a protective role of physical activity in joint health.

There were several limitations with our study. First, doctor-diagnosed arthritis was self-reported. Clinical or radiographic diagnosis is not easily implemented in observational studies, and studies have suggested a discordance between radiographic and clinical arthritis[36-38]. Several studies have indicated that self-reported diagnosis of arthritis has acceptable reliability for use in epidemiological studies[12,39]. NHIS arthritis estimates for the U.S. population also rely on self-reported diagnosis, and our survey question pertaining to arthritis was consistent with that of the NHIS and other population health surveys[12,18,19]. Second, participation in this survey required computer access. This could bias outcomes, as a younger generation is more likely to engage in an electronic survey. Third, it is difficult to isolate all factors that may affect arthritis (e.g., trauma, occupation, gait, and limb alignment). Additionally, it is not possible to conclude that distance running is not a risk factor for arthritis, as runners diagnosed with early arthritis may refrain from running. However, we included a large number of runners who completed >100 marathons with the thought that if running caused joint deterioration, we would likely detect it. It is important to note that these individuals may have potential protective qualities such as low BMI, male sex, or other genetic advantages that make it difficult to generalize results to the population at large. Ideally, this cohort will be followed to determine outcomes later in life.

Although existing evidence on whether distance running potentiates arthritis is inconclusive, we found a low prevalence of arthritis in active marathon runners. Age, family history, and surgical history independently predicted hip and knee arthritis in marathoners. There was no significant correlation between running history and arthritis, but an increasing number of marathons predicted decreased joint pain. Longitudinal studies are needed to determine the impact of marathon running on developing arthritis. We plan to prospectively follow the marathoners with redistribution of our survey to assess for changes in joint health over time.

Appendix

eA A table showing a health survey of hip and knee surgical procedures in marathon runners is available with the online version of this article as a data supplement at jbjs.org (http://links.lww.com/JBJS/E517). ■

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