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Impact of treadmill running on distal femoral cartilage thickness: a cross-sectional study of professional athletes and healthy controls

Pouria Azami^{1,3}, Alireza Ashraf¹, Omid Yousefi², Alireza Hosseinpour³ and Aref Nasiri^{1*}

Abstract

Purpose This present study aimed to assess the impact of treadmill running on distal femoral cartilage thickness.

Methods Professional athletes aged 20 to 40 years with a history of treadmill running (minimum 75 min per week for the past three months or more) and age-, sex-, and body mass index (BMI)-matched healthy controls were recruited. Demographics and clinical features of participants were recorded. Athletes were divided into subgroup 1 with less than 12 months of treadmill running and subgroup 2 with 12 months or more of treadmill running. Distal femoral cartilage thicknesses were measured at the midpoints of the right medial condyle (RMC), right intercondylar area (RIA), right lateral condyle (RLC), left medial condyle (LMC), left intercondylar area (LIA), and left lateral condyle (LLC) via ultrasonography.

Result A total of 72 athletes (mean age: 29.6 ± 6.6 years) and 72 controls (mean age: 31.9 ± 6.7 years) were enrolled. Athletes had significantly thinner cartilages in the RLC (2.21 ± 0.38 vs. 2.39 ± 0.31 cm, $p = 0.002$), LLC (2.28 ± 0.37 vs. 2.46 ± 0.35 cm, $p = 0.004$), and LMC (2.28 ± 0.42 vs. 2.42 ± 0.36 cm, $p = 0.039$) compared with the control group. Furthermore, cartilage thickness was significantly thinner in subgroup 2 athletes compared with the control group in the RLC (2.13 ± 0.34 vs. 2.39 ± 0.31 cm, $p = 0.001$), LLC (2.22 ± 0.31 vs. 2.46 ± 0.35 cm, $p = 0.005$), and LMC (2.21 ± 0.46 vs. 2.42 ± 0.36 cm, $p = 0.027$); however, subgroup 1 athletes did not have such differences. There was a weak negative correlation between total months of treadmill running and cartilage thickness in the RLC ($r = -0.0236$, $p = 0.046$) and LLC ($r = -0.0233$, $p = 0.049$). No significant correlation was found between the distal femoral cartilage thickness at different sites and the patients' demographic features, including age, BMI, speed and incline of treadmill running, and minutes of running per session and week ($p > 0.05$).

Conclusion Compared with healthy controls, professional athletes with a history of long-term high-intensity treadmill running had thinner femoral cartilages. The duration (months) of treadmill running was weakly negatively correlated with distal femoral cartilage thickness. Longitudinal studies with prolonged follow-ups are needed to clarify how treadmill running affects femoral cartilage thickness in athletes.

Keywords Athletes, Cartilage, Exercise, Knee Joint, Running, Ultrasonography

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What Is Known?

When physical activity is long-standing and vigorous, the risk of knee injury and subsequent initiation and progression of joint degeneration are higher. There are some differences in ground reaction force, kinetics, and kinematics between treadmill and non-treadmill running.

What Is New?

This unprecedented study found that athletes with a history of more than one year of high-intensity treadmill running had thinner cartilage thicknesses than the healthy controls in both knees.

Introduction

Exercise and physical activity benefit the whole body, especially the musculoskeletal system. Different guidelines have encouraged people to undertake physical activity [1, 2], which is believed to enhance general health, decrease obesity, increase self-esteem, and increase longevity. A sedentary lifestyle and obesity can lead to osteoarthritis, while moderate exercise can prevent this condition. However, when it comes to vigorous physical activity performed by elite or professional athletes, hazards can be expected.

The increasing global popularity of motorized treadmills spans various settings, including sports clubs, gyms, medical facilities, and home users. About 14% of American runners and elite athletes utilize motorized treadmills as part of their training routine [3]. Treadmill running improves bone quality, although its effect on articular cartilage is questionable [4]. The overuse of joints can result in cartilage degradation [5, 6]. The risk of knee injury and subsequent incidents like the progression of joint degeneration may be elevated when physical activity is long-standing, vigorous, or a part of professional sport. In such conditions, the knee joint is exposed to higher impact or torsional loading levels. Thus, articular cartilage breakdown and loss, as the main events in the pathogenesis of osteoarthritis (OA), can be expected. A number of researchers have assessed the potential effects of physical activity on cartilage degeneration and subsequent OA. Murry et al. found that middle-aged men who had participated in excessive athletic activity during adolescence had a higher risk of hip OA development [7]. In contrast, Cymet et al. pointed out that long-distance running might protect the joint against degeneration [8]. Overall, all athletes of competitive sports are believed to be at a higher risk of incidence and progression of hip, knee, and ankle OA resulting in hospital admission [9].

In recent years, physiatrists' use of musculoskeletal ultrasonography (US) has significantly increased. This modality is helpful in the diagnosis and treatment of musculoskeletal diseases and the evaluation of musculoskeletal structures. On the other hand, it is an inexpensive, non-invasive, convenient, and accessible modality

compared with magnetic resonance imaging and computed tomography.

The impact of physical activity on cartilage condition has been extensively studied, yielding variable and occasionally conflicting conclusions. Research indicates that engaging in regular physical exercise such as running and cycling for as little as two weeks can result in reduced cartilage volume among young, healthy adults [10]. It has been shown that running is associated with decreased cartilage thickness in marathon runners compared with sedentary individuals. However, some investigations suggest that running may induce transient and reversible changes in knee cartilage morphology and composition [11–13]. Furthermore, evidence suggests that running does not contribute to the formation of new cartilage lesions and has minimal effects on foot and ankle cartilage [11, 12]. The specific type, intensity, and frequency of physical activity are key determinants in how they affect different articular cartilages [14]. Although the effect of vigorous physical activity on the cartilage condition has been evaluated previously, there is no study evaluating distal femoral cartilage thickness in professional athletes who undertake treadmill running by US. Therefore, this study was designed to assess the effect of high-intensity treadmill running on distal femoral cartilage thickness and to investigate the predisposing factors of cartilage thickness loss.

The long-term impact of sustained treadmill running on joint health remains uncertain. To address this gap in knowledge, we aimed to evaluate the distal femoral cartilage thickness among professional athletes engaged in treadmill running using US. Consequently, this study aims to investigate the effect of high-intensity treadmill running on distal femoral cartilage thickness and explore potential factors contributing to cartilage thickness loss.

Methods

This study is reported following the STROBE guidelines [15].

Study participants

Professional athletes aged 20–40 years and age-matched healthy controls were recruited for this single-center cross-sectional study conducted in Iran, Shiraz, between August 2020 and March 2023. Athletes were selected from sports clubs. Healthy volunteers, who were chosen from the *Imam Reza Clinic* staff, and their relatives or participants who were referred to this clinic for any reason, constituted the control group. All included athletes had undertaken treadmill running for at least 75 min in vigorous intensity per week during the preceding three months or more. They ran on the treadmill once per practice day. Vigorous-intensity activity, defined as metabolic equivalents of tasks (MET) > 6 [2, 16], was determined

by achieving a heart rate of 70 to 85% of the maximal heart rate and experiencing labored breathing, indicated by the inability to speak more than a few words without pausing for breath during the talk test [17]. Participants were selected based on a BMI range of 18.5 to 30. They were excluded if they had a systemic disease (e.g., rheumatologic diseases, diabetes mellitus, thyroid disorders, and hormonal imbalances), knee trauma/pain/edema/malalignment or decreased range of motion, inflammatory or infectious arthritis, history of intra-articular injection or knee surgery, previous fracture of the femur, tibia, fibula, or patella, or injury to adjacent structures such as the hamstring or quadriceps muscles, cruciate ligaments, or menisci, as these may influence distal femoral cartilage thickness. Those who directly used supplements containing chondroitin sulfate and glucosamine, known to affect cartilage condition potentially [18], were excluded. The athletes did not participate in other individual or team sports, nor did they run on surfaces other than a treadmill, while the control group had no organized sports activities, including running. According to the 2003–2004 National Health and Nutrition Examination Survey (NHANES) [19], individuals engaged in high or intermediate occupational activity were excluded from the study. The majority of the athletes adhered to a diet typically high in protein, complex carbohydrates, healthy fats, and micronutrient-rich foods. Additionally, their coaches monitored external factors such as sleep hygiene across participants. All cases were informed about the study objectives and procedures and provided written consent to participate. The Institutional Ethics Committee approved the study protocol under the ethical number IR.SUMS.MED.REC.1399.536.

All of the athletes were physique bodybuilders. Physique is a relatively new bodybuilding division, mainly focusing on aesthetically pleasing physiques instead of muscle bulk, with the primary emphasis on upper extremity development [20]. Fitness, muscular shape, symmetry, confidence, and stage presence are other dimensions considered. The athletes engaged in similar targeted upper extremity exercises, such as arm curls, shoulder presses, chest flies, and rows, which are associated with minimal stress and direct loading on the knee. They regularly ran on the treadmills during the week to stay lean, fit, and well-proportioned without participating in other specific lower-extremity sports activities. They were professional athletes actively engaged in rigorous preparation for competitive bodybuilding events and possessed extensive backgrounds in bodybuilding competitions at various levels. Under the diligent supervision of their coach, treadmill running was a meticulously planned component of their training routine. Some athletes may have been new to this aspect of training, while

others had more experience, but all stuck to it to enhance their athletic performance.

Training protocols and data collection

Demographic and clinical features were noted, including age, weight, height, BMI, smoking habits, and occupation, as well as physical activity metrics such as the total months of treadmill running, mean minutes of running per session and week, and mean incline and speed of treadmill running. Athletes didn't follow a predetermined standardized protocol. However, their training regimens were highly similar due to shared environments, equipment, and athletic goals. Most athletes utilized Sole Fitness treadmills, which are reliable equipment commonly available in fitness facilities, and all used treadmills were shock-absorbent. The intensity of their training, assessed by mean heart rate (HR), mean respiratory rate, distance covered, and calories expended, varied from session to session and week to week according to their established training plan. Each session's speed, incline, and duration were not exactly uniform and varied depending on the specific training requirements. However, to align with the inclusion criteria of this study, athletes engaged in vigorous-intensity training, as previously defined by $MET > 6$, for a minimum of 75 min per week, ensuring consistency with recommended guidelines for cardiovascular health [2]. Their coach meticulously planned and supervised their running training regimen to ensure consistency and adherence to specific protocols. Most of the data, including the duration of every training session, mean incline, and speed of each session, were accurately recorded by the coach using treadmill console recordings. Additionally, insights from interviews with athletes provided further details on the perceived normal running routine.

Cartilage thickness measurement

All measurements were performed using the same US device by a linear probe (7–12 MHz, MyLab™Sigma, Esaote SpA, Genoa, Italy) in the clinic. Measurements were done 3 to 5 days after their last practice session. Participants were asked to sit comfortably on the examination table with their knees in maximum flexion. The physiatrist placed the probe in an axial position on the suprapatellar area. Then, the thickness of the medial (middle part), lateral (middle part), and intra-condylar sections of the distal cartilage of the femur on each side was measured and recorded. The distance between the sharp hyperechoic line at the cartilage-bone interface and the thin hyperechoic line at the synovial space-cartilage interface was measured as the cartilage thickness. The same physician collected all the demographic and clinical data, and a physiatrist expert in the musculoskeletal US performed all the measurements.

Previous studies [21, 22] have validated US as a reliable modality for visualizing femoral cartilage, demonstrating strong agreement between US and MRI measurements and affirming its reliability in assessing cartilage thickness. Similarly, investigations have shown that US measurements of femoral articular cartilage thickness exhibit good reproducibility, characterized by high inter-rater reliability and agreement with anatomical measurements [23, 24]. Several studies have employed this exact method in various populations of patients, indicating its reliability and applicability across different contexts [25, 26]. Although formal inter-rater assessments were not conducted in this study due to consistent measurements by the same sonographer, we ensured measurement consistency and reliability through rigorous adherence to a standardized protocol. The sonographer responsible for data collection underwent thorough training to ensure proficiency in measurement techniques. Additionally, to assess intra-rater reliability, a subset of measurements was randomly selected and independently reviewed by the same sonographer at different time points, demonstrating high consistency and reliability over time.

Specifically, the Intra-class correlation coefficient (ICC) values for the lateral condyle (0.779 [95% CI: 0.707–0.876]), the intercondylar area (0.843 [95% CI: 0.790–0.883]), and the medial condyle (0.834 [95% CI: 0.778–0.835]) were obtained [27].

Statistical analysis

The required sample size for each group was calculated using G*Power 3.1 software, employing an independent t-test [28]. With a power of 80%, a two-tailed significance level of 5%, and a medium Cohen-suggested effect size of 0.5 [29], a minimum sample size of 64 per group was needed.

The normality of the data was assessed by conducting the Shapiro-Wilk test. An independent t-test was

employed to compare cartilage thickness between study groups and between male and female athletes. It was also applied to evaluate other continuous variables such as age, BMI, and minutes of running per session and week between the groups. We conducted an analysis of variance (ANOVA) to compare cartilage thickness between the two different subgroups and controls. Following the ANOVA, a Bonferroni post-hoc test was utilized to evaluate between-group differences. We used the Pearson correlation test to examine the relationship between cartilage thickness and factors like age, weight, height, BMI, treadmill speed, and incline. Spearman correlation was applied to analyze the mean minutes of running per session and week and the total months of activity in relation to cartilage thickness among athletes. The correlation coefficients (r) were interpreted using thresholds commonly used in the literature: very weak (0.000–0.199), weak (0.200–0.399), moderate (0.400–0.599), strong (0.600–0.799), or very strong (0.800–1.000) [30]. We utilized the chi-square test to assess gender distribution among subgroups. Values are presented as mean and standard deviation (SD). All of the analyses were carried out using SPSS software version 26.0 (SPSS Inc., Chicago, Illinois, USA). A P-value of <0.05 was considered statistically significant.

Results

General characteristics

A total of 72 professional athletes with a mean age of 29.6 ± 6.6 years and BMI of 25.9 ± 3.1 kg/m² (52 men, 20 women) and 72 healthy controls with a mean age of 31.9 ± 6.7 years and BMI of 25.6 ± 2.6 kg/m² (52 men, 20 women) were enrolled in this study. The detailed demographic characteristics of the athletes and controls are shown in Table 1. There were no significant differences between the groups regarding age, sex, weight, height, BMI, and smoking status ($P > 0.05$).

Table 1 Presents the demographic information and physical activity data of the study participants

| Variables | Total Athletes (n=72) | Athletes Sub-group 1 (n=36) | Athletes Sub-group 2 (n=36) | Control Group (n=72) | P-value |
|--|-----------------------|-----------------------------|-----------------------------|----------------------|--------------|
| Age (years), mean \pm SD | 29.6 \pm 6.6 | 28.4 \pm 7.1 | 30.7 \pm 6.0 | 31.9 \pm 6.7 | NS |
| Sex, male/female, n (%) | 52 (72%)/20 (28%) | 26 (72%)/10 (28%) | 26 (72%)/10 (28%) | 52 (72%)/20 (28%) | NS |
| Weight (kg), mean \pm SD | 79.6 \pm 12.9 | 77.8 \pm 11.7 | 81.5 \pm 14.0 | 77.5 \pm 10.0 | NS |
| Height (cm), mean \pm SD | 170.1 \pm 30.2 | 168.9 \pm 30.1 | 171.3 \pm 30.7 | 171.7 \pm 27.9 | NS |
| BMI (kg/m ²), mean \pm SD | 25.9 \pm 3.1 | 25.6 \pm 3.2 | 26.1 \pm 3.0 | 25.6 \pm 2.6 | NS |
| Smokers, n (%) | 11 (15.2) | 6 (16.6) | 5 (13.8) | 14 (19.4) | NS |
| Speed (mph), mean \pm SD | 8.7 \pm 2.8 | 8.2 \pm 2.3 | 9.3 \pm 3.1 | - | NS |
| Incline (degree), mean \pm SD | 2.6 \pm 3.4 | 2.2 \pm 2.8 | 3.1 \pm 3.9 | - | NS |
| Mean running duration per session (minutes), mean \pm SD | 31.4 \pm 5.1 | 32.6 \pm 5.3 | 30.1 \pm 4.3 | - | NS |
| Mean running duration per week (minutes), mean \pm SD | 108.7 \pm 48.6 | 109.3 \pm 49.8 | 108.4 \pm 48.0 | - | NS |
| Total duration of running (months), mean \pm SD | 17.2 \pm 15.9 | 5.1 \pm 1.8 | 29.3 \pm 14.5 | - | 0.001 |

SD: standard deviation, BMI: body mass index, NS: not significant, kg: kilogram, cm: centimeter, mph: mile per hour. Subgroup 1: athletes with less than 12 months running, subgroup 2: athletes with equal or more than 12 months running

Table 2 Distal Femoral Cartilage Thickness Measurements of Participants

| Mean thickness/ SD (cm) | Total Athletes | Control | P-value |
|-------------------------|----------------|-------------|---------------|
| RLC | 2.21 ± 0.38 | 2.39 ± 0.31 | 0.002* |
| RIA | 2.31 ± 0.50 | 2.42 ± 0.48 | 0.170 |
| RMC | 2.30 ± 0.39 | 2.38 ± 0.38 | 0.201 |
| LLC | 2.28 ± 0.37 | 2.46 ± 0.35 | 0.004* |
| LIA | 2.33 ± 0.54 | 2.46 ± 0.48 | 0.077 |
| LMC | 2.28 ± 0.42 | 2.42 ± 0.36 | 0.039* |

RLC: Right Lateral Condyle, RIA: Right Intercondylar Area, RMC: Right Medial Condyle, LLC: Left Lateral Condyle, LIA: Left Intercondylar Area, LMC: Left Medial Condyle). * Independent t-test was used to compare cartilage thickness in total athletes and controls

Cartilage thickness comparison between all athletes and controls

Table 2 shows the mean distal femoral cartilage thickness

between all athletes and controls. Although the athletes had thinner femoral cartilage thickness values at all measured sites compared with the controls, the difference only reached statistical significance in the RLC (2.21 ± 0.38 cm vs. 2.39 ± 0.31 cm, $p=0.002$), LLC (2.28 ± 0.37 cm vs. 2.46 ± 0.35 cm, $p=0.004$), and LMC (2.28 ± 0.42 cm vs. 2.42 ± 0.36 cm, $p=0.039$).

There was a weak, significant negative correlation between the duration of treadmill running and distal femoral cartilage thickness in the RLC ($r = -0.236$, $p=0.046$) and LLC ($r = -0.233$, $p=0.049$), indicating that as the duration of treadmill running increases, the thickness of cartilage decreases (Fig. 1). However, no significant correlation was found between the distal femoral cartilage thickness at different sites and the athletes' age, BMI, speed and incline of treadmill running,

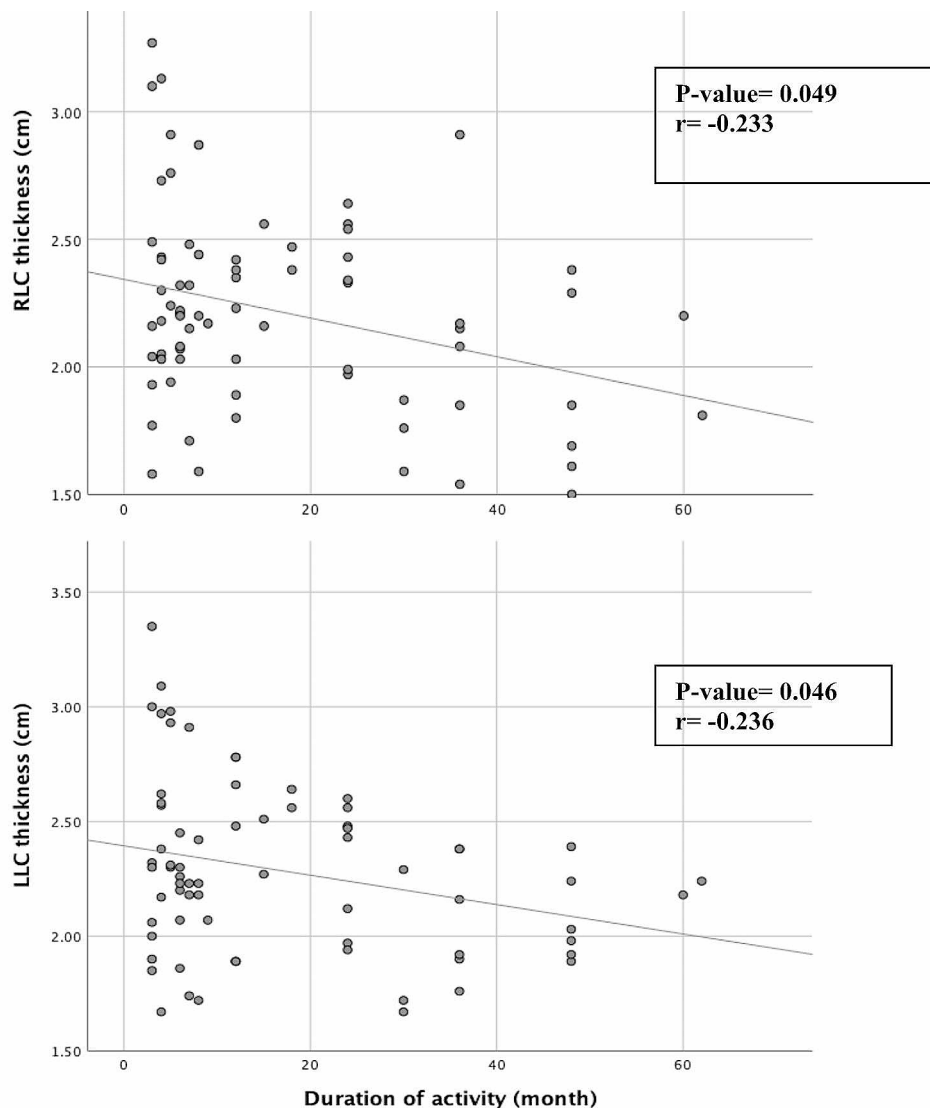


Fig. 1 Scatter plot depicting the correlation between duration of running and cartilage thickness. RLC: Right Lateral Condyle, LLC: Left Lateral Condyle, r: Correlation coefficient

and minutes of running per session and week ($p > 0.05$). Female athletes had significantly thinner distal femoral cartilages in RLC (2.29 ± 0.37 cm vs. 1.98 ± 0.33 , $p = 0.002$), RIC (2.42 ± 0.49 cm vs. 2.02 ± 0.40 cm, $p = 0.002$), LLC (2.36 ± 0.36 cm vs. 2.06 ± 0.30 cm, $p = 0.002$) and, LMC (2.34 ± 0.042 cm vs. 0.14 ± 0.40 cm, $p = 0.008$) than male athletes.

Subgroup analyzing

Table 1 shows demographic comparisons between subgroup 1, 2 and controls. To examine how different durations of running, including short-term (less than 12 months) and longer-term durations (12 months or more) could influence cartilage thickness, a subgroup analysis was performed. Subgroup 1 consisted of 36 athletes, (26 men and 10 women) with a mean age of 28.4 ± 7.1 years, and a mean duration of treadmill running of 5.1 ± 1.8 months. Subgroup 2 also comprised 36 athletes (26 men and 10 women) with a mean age of 30.7 ± 6.0 years and, a mean duration of treadmill running of 29.3 ± 14.5 months (Table 1). The mean cartilage thickness for each subgroup is provided in Fig. 2. The analysis revealed that there were no significant gender distribution differences among the subgroups ($p > 0.05$). When comparing

the subgroups of athletes with the controls, the analysis showed significantly thinner cartilage thickness in the RLC (2.13 ± 0.34 cm vs. 2.39 ± 0.31 cm, $p = 0.001$), LLC (2.22 ± 0.31 cm vs. 2.46 ± 0.35 cm, $p = 0.005$), and LMC (2.21 ± 0.46 cm vs. 2.42 ± 0.36 cm, $p = 0.027$) in subgroup 2 (≥ 12 months of treadmill running) compared with the controls (Fig. 2). No significant differences were observed in cartilage thickness between subgroup 1 and 2, or between subgroup 1 and the control group.

Discussion

The aims of this study were to investigate the effects of treadmill running on knee cartilage thickness in professional athletes compared with non-athlete individuals, by using US, and to determine whether there is a correlation between the total months of treadmill running and cartilage thickness in various knee regions. One main finding of this study was that athletes with over one year (mean 29, SD 14.5 months) of treadmill running experience had significantly thinner cartilage thickness in the majority of knee regions compared with non-athlete controls. Another finding was that a weak negative correlation between the total months of treadmill running and distal femoral cartilage thickness in different knee regions

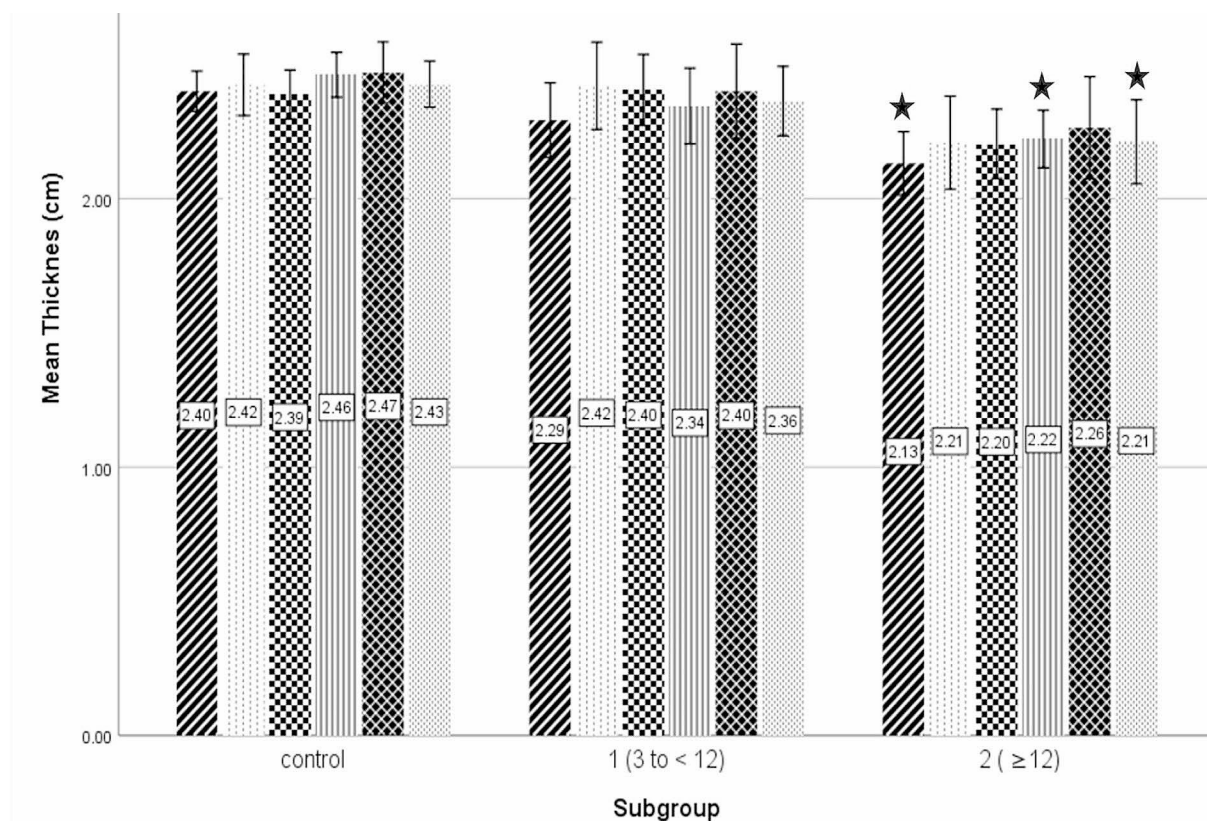


Fig. 2 The mean distal femoral cartilage thickness in various regions of the knees within subgroups is depicted at the center of each bar. RLC: right lateral condyle, RIA: right intercondylar area, RMC: right medial condyle, LMC: left medial condyle, LIA: left intercondylar area, LLC: left lateral condyle; Subgroup 1: 3 to <12 months of treadmill running, Subgroup 2: ≥ 12 months of treadmill running

among physique bodybuilders was revealed. No significant correlations were observed between cartilage thickness and treadmill incline, speed, BMI, or mean duration of minutes of running per session and week.

Prior studies have also examined the acute effects of treadmill running on femoral cartilage thickness. Güvener et al. found no significant difference in absolute and percent change of cartilage thickness following one session of treadmill jogging compared with walking and resting in healthy participants [31]. Conversely, Harkey et al. reported significant medial knee cartilage deformation in healthy participants during treadmill running and walking compared with rest [32]. The present study primarily focuses on the long-term effects of treadmill running rather than immediate changes after a single session, and it indicates a weak negative correlation between total months of treadmill running and cartilage thickness. It's important to note that while acute changes in cartilage thickness are often reversible, long-term participation in treadmill running may lead to permanent alterations, which is beyond articular cartilage adaption capacity [33]. From a molecular perspective, this chronic process involves various changes in cartilage structure, including chondrocyte hypertrophy, cartilage zone clustering, small fissures in the cartilage, increased expression of the aggrecan gene, reduced expression of matrix metalloproteinase-2 (MMP-2) and mono-iodoacetate, loss of glycosaminoglycans (GAGs), and resorption of periaricular bone [34–37].

The increasing global popularity of motorized treadmills spans various settings, including sports clubs, gyms, medical facilities, and home users. About 14% of American runners and elite athletes utilize motorized treadmills as part of their training routine [3].

In this study, only athletes with high-intensity running training were included and were shown to have less cartilage thickness, especially those with longer experience of running, compared with controls. Intense physical activities, such as treadmill running, exert significant stress on articular cartilage, potentially leading to cartilage strains and reduced thickness in the tibiofemoral joint [38, 39]. While moderate-intensity running may help maintain cartilage integrity, high-intensity treadmill running can alter the subchondral bone composition, making it stiff and fragile, thus increasing the mechanical load on overlying cartilage and promoting degeneration [40, 41]. Prior research predominantly explores the impact of high-intensity treadmill running on articular cartilage using animal models. Kotwal et al. observed significant decreases in cartilage thickness and volume in mice subjected to excessive treadmill running, suggesting a role of proteoglycan (PG) loss in these changes [42]. A four-week high-intensity treadmill regimen also induced irreversible cartilage catabolism and weakened anabolism in

mice [43]. Tang et al. demonstrated femoral articular cartilage degeneration in rats following six weeks of strenuous treadmill running [44]. Understanding the impact of activity intensity is vital, as higher weight-bearing loads can render articular cartilage more susceptible to degenerative changes [5, 45, 46].

Although this study does not directly measure the distance covered by athletes, there was no difference between subgroup 1 and 2 in either minutes per session or week of running or running speed. However, there was a difference between subgroup 2 and controls regarding the thickness of cartilage, yet not between subgroup 1 and controls, implying that it may be the history of running that might affect this. This aligns with the notion that prolonged participation in high-intensity activities, such as long-distance running, may impact knee joint health over time [47]. Therefore, while this study does not assess the exact distance covered, it provides insights into the potential effects of sustained treadmill running on knee cartilage thickness, especially over a year. The Hinterwimmer study noted significant cartilage loss in the lateral femoral cartilage after six months of a training program followed by a marathon, particularly among marathon beginners [48]. Sohn and Micheli investigated former cross-country runners, contrasting them with swimmers as a control group, yet found no discernible link between long-distance running and the development of OA [49]. Chakravarty et al. tracked knee OA progression over two decades in middle-to-older-aged long-distance runners versus healthy non-runners [50]. Despite assessing 55 long-distance runners and 53 controls with a mean age of 58 years, they found no increased radiologic OA progression in long-distance runners. The inconsistency of these results with the present study may stem from differences in running surfaces, as treadmill running differs from ground running in various aspects. A systematic review by Semaan et al. highlights that while motorized treadmill running and overground running generally yield comparable outcomes across measures like spatiotemporal, kinematic, kinetic, electromyographic, and energy consumption, disparities emerge in certain aspects such as kinematics, kinetics, ground reaction force components, and electromyographic responses, particularly with long-term, high-intensity usage [51, 52]. Also, some animal studies have reported positive effects of treadmill running on knee cartilage health [40, 41, 45, 46]. However, disparities in methodology, excluding the inherent differences due to animal nature, may contribute to variations in results compared with this study. Nonetheless, accurately predicting the effect of treadmill running on knee cartilage remains challenging.

This study investigated various parameters, including incline running, treadmill speed, BMI, gender, and

side differences, in relation to knee cartilage thickness. The findings largely align with prior research, with some distinctions noted. Regarding treadmill speed, the present study found no significant impact on knee cartilage thickness, consistent with the findings of Rios et al. [53]. We also observed gender differences in cartilage thickness, consistent with previous researches, where female athletes tended to have thinner cartilage compared with males [54, 55]. While no correlation was found between incline running on a treadmill and cartilage thickness in this study, it is suggested that incline walking may positively affect cartilage degeneration by increasing abduction knee moment [56]. We found no significant correlation between BMI and cartilage thickness, contrary to studies suggesting a link between higher BMI and thinner cartilage [53, 57]. Notably, all athletes in this study had a BMI under 30 kg/m². It is also indicated that individuals with higher BMI (>30 kg/m²) showed increased cartilage strain during walking compared with those with normal BMI, suggesting the possibility that the meniscus may not effectively distribute loads to mitigate the effects of obesity [57]. Furthermore, this study did not find discrepancies in cartilage thickness between the left and right distal femoral sides, contrary to the study by Adam et al. [58], which found that the right lateral side was thicker than the left, possibly due to most people being right-footed.

Interestingly, the present study found no correlation between daily minutes of treadmill running and cartilage thickness. Research suggests that moderate daily exercise may benefit cartilage matrix composition, but not thickness, in healthy animals, while high exercise doses could have negative effects [59]. Notably, shorter durations with more frequent sessions of treadmill activity per day may have chondroprotective effects, as demonstrated by Yang et al., where 60 min of daily treadmill running completed in three sessions was found to be more beneficial for cartilage health compared with fewer sessions with longer durations [60]. These disparities may suggest the need for further investigation into the complex relationship between these parameters and knee cartilage health. It is attempting to assume that degenerative articular cartilage changes may appear when high-intensity treadmill running continues for a long-term of months, especially in weight-bearing femoral cartilage among physique bodybuilders. High intensity and overuse are responsible in this regard, as physique bodybuilders with more than one year of vigorous-intensity treadmill running had significantly thinner distal femoral cartilages in both knees' lateral and medial sides.

Limitations

Relying solely on a single methodological approach may limit the depth of this study's analysis. Incorporating

multi-modal research methods could offer a more comprehensive understanding of the phenomenon under investigation. For example, histological and molecular evaluations using multiple imaging modalities may improve understanding of the topic and help to explore the underlying mechanisms sufficiently. However, we must consider such assessments' ethical issues, costs, and challenges when dealing with human participants. In addition, despite the efforts to apply strict inclusion and exclusion criteria, controlling all variables is challenging. For example, treadmill devices may have different shock absorbent capabilities. It's also crucial to highlight the potential impact of other possible limited lower extremity physical activity and the indirect effects of upper extremity activity on knee cartilage through biomechanical and systemic responses. However, such impacts seem minimal and inconclusive. Most importantly, the present study was retrospective. Although an attempt to utilize documented information with the assistance of their coaches while collecting information regarding athletes' physical activity was performed, it is important to acknowledge that the possibility of recall bias cannot be completely excluded. so future longitudinal studies with prolonged follow-ups are necessary to fix the limitations and draw cause-and-effect conclusions between vigorous-intensity treadmill running and cartilage thickness changes.

Conclusion

According to the findings of this study, we conclude that vigorous sustained treadmill running may have adverse effects on knee cartilage in athletes, specifically those with more than a year of running, despite the suggested priority of a more physically active lifestyle compared with a sedentary one. Duration of treadmill running, rather than incline and, speed of running, age, and BMI, was negatively correlated with distal femoral cartilage thickness. To optimize training and prevent adverse effects, identifying the conditions under which they occur is crucial. Factors such as intensity, frequency of training, type of physical activity, and environmental variables like treadmill settings play significant roles in this optimization process.

Abbreviations

| | |
|-------|----------------------------|
| RLC | Right lateral condyle |
| RIA | Right intercondylar area |
| RMC | Right medial condyle |
| LLC | Left lateral condyle |
| LIA | Left intercondylar area |
| LMC | Left medial condyle |
| BMI | Body mass index |
| OA | Osteoarthritis |
| SD | Standard deviation |
| MMP-2 | Matrix metalloproteinase-2 |
| GAG | Glycosaminoglycan |
| PG | Proteoglycan |

ICC Intra-class correlation coefficient
US Ultrasonography

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s13102-024-00896-4>.

Supplementary Material 1

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Author contributions

Conceptualization and study design: [AA and AN]; Acquisition of data: [PA and AN]; Formal analysis and investigation: [PA and OY]; Writing-original draft preparation: [PA]; Writing-review and editing: [All authors]; Supervision: [AA and AN]. All authors read and approved the final manuscript; Revision preparation: [PA and AH].

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Data availability

The datasets utilized and/or analyzed during the present study are accessible upon reasonable request from the corresponding author.

Declarations

Ethics approval and consent to participate

The research was carried out in adherence to the principles outlined in the Declaration of Helsinki and received approval from the Ethics Committee of Shiraz University of Medical Sciences. All participants in the study provided written informed consent prior to their involvement.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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