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Review Article
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Evaluation of MR Images of the Ankle and Foot in Response to Long-Distance Running: A Systematic Review

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Abstract

Background: It has remained controversial on whether excessive loadings imposed on the ankle and foot complex during long-distance running have a deleterious effect. The aim of this systematic review is to determine whether long-distance running causes any visible changes of the ankle and foot on magnetic resonance imaging (MRI).

Methods: Scopus, Web of Science, Embase and Ovid Medline were searched using key terms in relation to MRI findings of the ankle and foot in response to long-distance running, published between 1990 and 2016. The final search was conducted on 19 September, 2016. Studies were identified using inclusion and exclusion criteria. Methodological quality was assessed using a modified Quality Index.

Results: The database search initially produced 551 articles and it was screened based on inclusion and exclusion criteria, finally resulting in four articles. Edema was reported in the talus, tibia, calcaneus, navicular, cuboid and cuneiforms. A significant alteration in signal intensity and/or edema was appeared in the calcaneus at the Achilles insertion point, intraosseous and subcutaneous over long-distance running. The diameter of Achilles tendon was also significantly increased. However, when comparing between race finishers and non-finishers, the plantar aponeurosis and subcutaneous were only significantly different, reporting a high rate of edema in non-finishers. Additionally, one study adopted T2* mapping and found significant alteration in T2* values in tibiotalar cartilage, but the value was unexpectedly decreased in the middle of long-distance running.

Conclusion: This is the first systematic review to determine the effect of long-distance running on the ankle and foot using MRI. It shows that long-distance running may cause subtle pathological and biochemical changes in the ankle and foot, including the talus, tibia, the distal and proximal group of tarsal bones, 5th metatarsals, soft tissues and the Achilles tendons. However, there is no evidence that these changes have clinical relevance.

Keywords: MRI; Long-distance running; Achilles tendon; Ankle cartilage

Introduction

Over the past decades the number of amateur participants in long-distance running events (i.e., 5 km-42 km) has been increasing, becoming one of the most popular fitness activities [1]. Despite obvious health benefits, it remains controversial whether the repetitive and excessive loading imposed on the lower limbs has a deleterious effect on the joints. According to *in vitro* laboratory research, acute and cumulative impact and torsional joint loading may cause articular damage and joint dysfunction [2,3]. An animal model study found degenerative articular alterations in the knee joint under simultaneous shear stress and axial overloading [4]. Repetitive loads also provoked progressive cartilage degeneration on patellar osteochondral specimens [5]. In the humans, although this excessive loading is generally well absorbed and distributed by muscles, ligaments, and cartilages, the lower limbs are still exposed to a substantial burden during long-distance running, especially when the muscle becomes fatigued. Thus, excessive loading with long duration imposed on the lower limb joints may lead to running-related injuries such as tibial stress syndrome, metatarsal stress syndrome, patellar tendinitis, Achilles tendinitis and plantar fasciitis.

Numerous studies have employed MRI to examine pathological, morphological and/or biochemical changes in response to long-distance running, but such studies have mainly focused on the knee joint [6-22]. Many of these studies found significant changes including bone marrow edema (BME), joint effusion and cartilage thickness and volume, but such changes seem to return to baseline after a rest period (1 h to 8 weeks) [13,20,23]. While the ankle and foot complex is one of the most common injured sites in response to long-distance running [24,25], there is no study systematically determining the effect of long-distance running on the ankle and foot. Therefore, the objective of this systematic review is to present an overview of the literature describing the evaluation of MRI of the ankle and foot in response to long-distance running.

Methods

Search strategies and selection process

This systematic review was conducted and reported based on principles from the PRISMA guidelines [26]. Studies were identified from searches of Scopus, Web of Science, Embase and Ovid Medline, published in English between 1990 and present. The final search was conducted on 19 September 2016. The following search terms were used: 1) MRI OR “magnetic resonance imaging, AND 2) running OR run OR runners OR jog OR jogging OR marathon OR long distance OR distance run, AND 3) foot OR feet OR ankle.

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Titles and abstracts of all identified studies were initially screened by a single reviewer (HKK) using specific eligibility criterion as shown below and another reviewer (SAM) checked this process. Full articles were retrieved from this initial screening, and full-text was read for further narrowing down. Reference lists from the full-text articles were also examined for additional relevant articles.

Eligibility criteria

Studies were included if it meets all of the following inclusion criteria: 1) the duration of long-distance running should be at least 30 min; 2) long-distance running can be performed within a day or over several days; 3) MRI should be undertaken before (baseline) and after (or during, follow-up) long-distance running; 4) the outcome of interest was MRI findings of the ankle and/or foot; 5) only healthy and asymptomatic populations were included. Studies were excluded if: 1) they were cadaver or animal studies; 2) full-text articles were written in non-English language; 3) studies were review, conference abstract, and press papers.

Data extraction

Data extracted included study design, number of participants, participant demographics (gender, age, body mass index (BMI), injury history of lower limb and training history if available), inclusion and exclusion criteria, types of long-distance running (speed, distance, and environment if available). MRI findings, magnetic field, MRI sequences, body sites for MRI, the time points of MRI for baseline and follow-up were also noted. Data was extracted by a single reviewer (HKK) and was checked by a second reviewer (SAM). The included study characteristics were given in Table 1.

Methodological quality assessment

A modified version of the Quality Index (QI) [27] was used to evaluate the methodological quality of the selected studies. This original tool includes 27 questions for evaluation of reporting, external validity, internal validity (bias and confounding) and power. Of these 27 questions, the power-related question (question 27) was excluded because it was not applicable to the current review [28]. Each question was rated as 'yes', 'no' or 'unable to determine'; if the answer was positive, it scored one, and otherwise zero. Question five was the exception that had three ratings: 2='yes'; 1='partially'; and 0='no'. Thus, 27 were the maximum score from the QI. Studies were considered to be high-quality if the summed QI was ≥ 80%; studies were considered to be moderate-quality if the QI was ≥ 47% and <80%; studies were considered to be poor-quality if the QI was <40% [29-31].

Results

With initial search terms, 533 articles were produced after removing the duplication. All abstracts and titles were screened, and 523 articles were removed based on the eligibility criteria. Ten articles were identified as potentially relevant to the current study and six articles were removed after reading full-text. Four articles were finally selected in the current review. A flow diagram of selection process and search results was shown in Figure 1.

Description of studies

Four studies [32-35] investigating the effect of long-distance running on the ankle and foot complex using MRI were included in this systematic review. All the studies compared MRI results between baseline and follow-up within the same participants. None of these studies performed a single long-distance running. Two studies [33,35] performed an ultra-marathon race (4486 km-4487 km) for about consecutive 64 days and one study [32] conducted 30 min outdoor run per day for consecutive seven days. The remaining study [34] conducted seven-month intensive training, consisting of six training sessions per week and two major international races. All the studies recruited healthy adults without gender restriction. The participant's fitness levels varied from sedentary individuals to professional runners. The details of demographic information of participants and inclusion and exclusion criteria are provided in Table 1.

MRI protocol

All the selected studies repeated MRI before and after or during long-distance running. The magnetic field of all studies was 1.5 T (Tesla). Two studies [32,34] conducted MRI examination twice, once at baseline and one during follow-up. Baseline MRI was performed prior to initiation of running [32] or one month prior to a training season [34]. Follow-up study was conducted 10-20 h following exertion [32] or one month after the completion of the training season [34]. Another two studies [33,35] performed MRI examination repetitively (five times in total), before and during long-distance running, approximately every 900 km-1000 km. Two studies used a dedicated foot coil with 8 channels [33,35], while one study adopted a head coil [32] and the remaining study [34] did not describe their technique. T2* mapping was performed in one study [35] to assess biochemical changes in the tibiotalar cartilage along with measuring its thickness. One study determined [33] the Achilles tendon diameter, signal intensities in the tendons, bones and soft tissue in the ankle and hind foot regions. Two remaining studies [32,34] assessed BME of the ankle and foot and one [34] of these included multiple joints including the hips, knees, ankles and feet. Details of MRI protocols can be found in Table 1.

MRI grading system

Three [32,34,35] of four studies adopted quantitative grading systems. One study [35] used the Outer bridge MRI grading system which was modified by Mosher [36]. Another study [34] used the Knee Osteoarthritis Scoring System which was modified and validated by Kornaat et al. [37]. One study [32] used a four-point grading scale system, but further details were not provided.

MRI findings

Ankle bones: Two [32,34] of four studies assessed edema in ankle bones including talus, tibia and/or fibula. These two studies reported that a number of participants (30%-88%) already had edema on the talus [32,34] and tibia [34] at baseline. The fibula was observed by one study [34], but no visible pathology was seen at baseline or follow-up. For sedentary individuals [32], the edema scores in the talus were significantly increased at follow-up. For elite runners [34], the amount of edema showed fluctuation, with new lesions appearing and old lesions disappearing, when comparing baseline with follow-up. However, this study [34] did not describe which bones had these fluctuating appearances.

Foot bones: Three [32-34] of four studies assessed bone edema and/or signal intensity in the foot bones. Two studies [32-34] reported that bone lesions already existed at baseline. Of these, one study [32] indicated that the changes in edema scores and the number of affected bones (i.e., the calcaneus, navicular, cuboid, 5^{th} metatarsal) were significantly increased at follow-up. Another study [34] reported that BME on os calcaneus, os naviculare, os cuboideum and os cuneiforme were observed. However, information of which bones had changed through baseline and follow-up was not provided. Another study [33]

Authors	Participants Demographics					Inclusion-Exclusion Criteria	Running Types	MRI			
	Number	Gender (F:M)	Weight, Height (or BMI) (average ± SD or range)	Age (average ± SD or range)	Runners Level			MRI Time Points	Magnetic Field	MRI Sequences	Scan Sites
Trappeniers et al. [32]	10	2:8	72.9 kg (55-88) 1.79 m (1.62-1.88)	25.7 (22-30)	Sedentary individuals	• No history of ankle trauma • No use of medication • No flat foot, varus and valgus deformity	30 min outdoor run per day for 7 consecutive days	• Baseline • 10-20 h follow-up	1.5 T	• Sagittal and transverse STIR	Both feet
Freund et al. [33]	22	2:20	70.9 kg (± 11.3) 1.74 m (± 0.09)	49.1 (± 11.5)	n.s.	• Participation in the ultra-marathon race • No contraindications for MRI.	4487 km ultra-marathon	• Baseline • Approx. every 1000 km during the race	1.5 T	• Sagittal fat saturated STIR	Both feet
Kornaat et al. [34]	16	3:13	67.8 kg (± 6.8) 1.82 m (± 0.06)	23 (± 2.7)	National level of mid- and long-distance runners	• Top 8 placement at the European Championships or top 12 placement at the World Championship • No significant lower limb injuries.	7 months intensive training season	• Baseline (1-month before starting the training season) • One month follow-up	1.5 T	• Coronal T2-weighted fat-suppressed • Coronal 3D SPACE fat-suppressed	Both hips, knees, ankles
Schütz et al. [35]	13	1:12	73 kg (± 11.3) 23.4 kg/m² (± 2.5)	45.4 (± 10.7)	n.s.	• Participation in the ultra-marathon race • Race finishers • No contraindications for MRI.	4486 km ultra-marathon	• Baseline • Approx. every 900 km during the race	1.5 T	• FLASH T2*-weighted GRE • TIRM • Fat-saturated PD-weighted	Right ankle

Note: F: Female; M: Male; T: Tesla; n.s.: Not Specified; SPACE: Sampling Perfection with Application Optimized Contrasts using different flip angle evolution; FLASH: Fast Low Angle Shot; STIR: Short Tau Inversion Recovery; GRE: Gradient Echo; TIRM: a Turbo-Inversion-Recovery-Magnitude; FLASH: a Fast Low Angle Shot; PD: Proton Density

Table 1: Study characteristics.

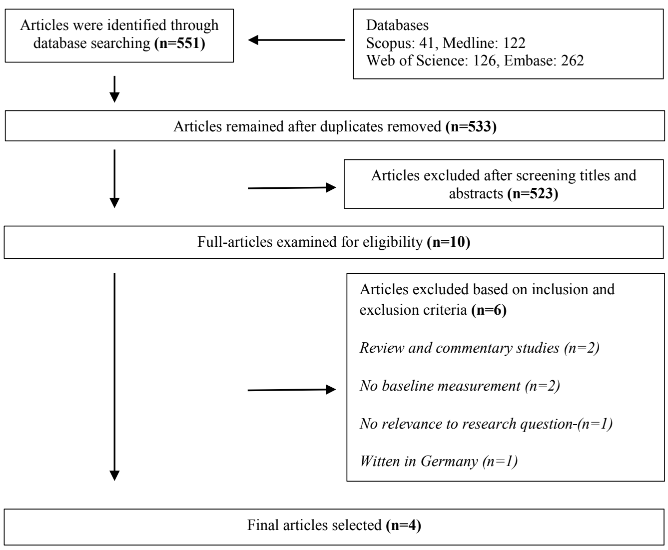

Figure 1: Flow diagram of study selection process.

examined hind foot bones and soft tissues. This study reported that the number of bone lesions (not specific to which bones), signal intensity in the calcaneus at the Achilles tendon insertion, and signal intensity in an innocuous area of the calcaneus were significantly increased over long-distance running.

Tibiotalar cartilage-T2* mapping and thickness: One of four studies [35] used T2* mapping of the tibiotalar cartilage. One baseline and four follow-up scans were conducted over long-distance running. T2* signal was significantly increased in the tibial plafond and talar dome cartilage at the first and second follow-up. However, a significant T2* decrease was observed as the running distance increased with the third and fourth follow-up scans. The thickness of this tibiotalar cartilage was also measured by the same study [35], but it did not show any significant changes.

The Achilles tendon: One study [33] described the Achilles tendon with regards to diameter, signal intensity and lesions. Over long-distance running, the diameter of Achilles tendon was significantly increased from a mean of 6.8mm to 7.8mm. When comparing the Achilles tendon in race finishers with non-finishers (aborting the race), there was no significant difference.

Plantar aponeurosis: One study [33] assessed signal intensity and edema in the plantar aponeurosis. Over long-distance running, no significant changes were observed. However, when comparing race finishers with non-finishers, non-finishers showed significantly higher rates of edema in the plantar aponeurosis than race finishers.

Subcutaneous tissues: One study [33] determined significantly increased subcutaneous edema over long-distance running. A comparison between race finishers and non-finishers showed that non-finishers had significantly higher rates of edema in the subcutaneous space than race finishers.

Subchondral bone: Subchondral bone was assessed by one study [35]. No changes were observed over long-distance running.

Intraosseous signal: The intraosseous signal was assessed by one study [33] and this value was significantly increased over long-distance running. However, when it compared between the race finishers and non-finishers, there was no different.

Reliability of MRI findings

MRI scans were interpreted by at least two radiologists [32,33,35], except one study [34] assessed by a single radiologist. To calculate correlation coefficient on the intra- and inter-rater reliability, two studies [33,35] used Lambda as proposed by Jepsen et al. [38]. The values for both studies were ranging from 0.88 to 0.998, indicating that the reliability was excellent. Another study [34] reported the intra- and inter-rater reliabilities (intraclass correlation coefficient) and the values were 0.93 and 0.91, respectively. One remaining study [32] did not provide any information on the reliability of MRI findings.

Methodological quality assessment

Moderate quality was found for the four identified studies [32-35] (Table 2). Of the four sub-scales, the quality of reporting was generally addressed well. All studies scored zero on questions 8 (reporting), 12 (external validity), 14, 15 (internal validity on bias) and 24, 25 (internal validity on confounding). Question 19 (internal validity on bias) was also scored poorly. All studies well addressed on questions 1-7 (reporting), 13 (external validity), 16-18, 20 (internal validity on bias) and 26 (internal validity on confounding).

Discussion

The findings of this review indicate that long-distance running may cause subtle changes with regards to BME, signal intensity, Achilles tendon size and within the soft tissue space in the ankle and foot. However, there is no described clinical correlation or relevance given to these findings.

Among the ankle bones, the talus and tibia seem to be affected by long-distance running. Studies included in this review [32,34] highlighted the high rate of BME in the talus and tibia for both sedentary individuals and elite runners. Following seven days of running for 30-min per day in sedentary individuals [32], 50% of participants showed edema involving in the talus, calcaneus, navicular, cuboid and 5th metatarsal. However, as this study did not provide any information about running conditions such as speed, surface, shoes, and running techniques, it is unclear if the edema occurs due to other constitutional factors. Another study [34] of 16 elite runners evaluated multiple lower limb joints before and after a seven month training season, reporting that the number of lesions fluctuated. However, information of which bones had changed through baseline and follow-up was not provided. Moreover, there were a few clinical complaints during the season, but these did not appear to relate to the presence of BME lesions. Thus, the incidental BME seen on MRI scan may have no clinical relevance. The possibility that the runners were exposed to other types of training (i.e., weight training and plyometric training) during the seven months should be also considered as a confounder.

Several foot bones including the calcaneus, navicular, cuboid and cuneiform also seem to be influenced by long-distance running. The tarsals and metatarsals are typically involved in overuse injuries [39]. This finding is consistent with biomechanical studies assessing the foot plantar pressure before and after long-distance running. These studies found that the loading under the 4th and 5th metatarsals and the heel were significantly increased [40-42]. Thijs et al. [43] also reported that the greater plantar pressure under the metatarsals and lateral heel regions can be related to patellofemoral pain in runners.

With regards to the tibiotalar cartilage, one study [35] employed T2* mapping to assess quantitative biochemical cartilage analysis along with thickness changes in response to ultra-marathon. The

Sub-areas	Questions	Authors			
		Trappeniers et al. [32]	**Freund et al. [33]**	**Kornaat et al. [34]**	**Schütz et al. [35]**
Reporting	1. Described hypothesis/aims clearly?	1	1	1	1
	2. Described main outcomes clearly?	1	1	1	1
	3. Described characteristics of participants?	1	1	1	1
	4. Described intervention?	1	1	1	1
	5. Described the distribution of principal confounders?	1	1	1	1
	6. Described main findings?	1	1	1	1
	7. Provided estimates of the random variability for main outcome?	1	1	1	1
	8. Reported all adverse events?	0	0	0	0
	9. Described characteristics of participants lost to follow-up?	1	0	1	1
	10. Reported actual probability values for the main outcome?	1	1	0	1
External validity	11. Were participants asked to join in the study representative of the entire population?	0	1	0	1
	12. Were participants preparing to participate representative of the entire population?	0	0	0	0
	13. Was the intervention representative of that in use in the majority of the population?	1	1	1	1
Internal validity bias	14. Did participants have no way to know which intervention they received?	0	0	0	0
	15. Were the main outcomes of intervention blind?	0	0	0	0
	16. Was it clear if results were based on “data dredging”?	1	1	1	1
	17. Was the time period of follow-up same?	1	1	1	1
	18. Used appropriate of statistical tests?	1	1	1	1
	19. Was compliance with intervention reliable?	1	0	0	0
	20. Described the main outcome measures clearly?	1	1	1	1
Internal validity confounding	21. Were participants in different groups recruited from the same population?	0	0	0	0
	22. Were participants in different groups recruited from the same time period?	0	0	0	0
	23. Were participants randomised to intervention group?	0	1	0	1
	24. Concealed the randomised intervention?	0	0	0	0
	25. Adjusted confounding adequately?	0	0	0	0
	26. Reported losses of the participant to follow-up?	1	1	1	1
QI scores total (% of maximum score)		**16 (59%)**	**16 (59%)**	**14 (52%)**	**17 (63%)**

Table 2: Modified quality index (QI) to assess quality of methodology.

articular cartilage of the ankle is much thinner and stiffer than the knee; probably due to this reason, no morphological changes were observed in the current review. Another possible reason for no thickness change could be the absence of controlling for diurnal effects. Unlike the ankle joint, the knee cartilage generally loses thickness and/or volume even after shorter distance running (5 km-20 km) for both trained and recreational runners [13,15,19,22,44] and all these knee studies made efforts to minimize the diurnal effect.

In the current selected study [35], T2* values were significantly increased in almost all regions of the tibial plafond and talar dome cartilage during the initial 2000 km-2500 km. However, a significant T2* decrease was observed as the running distance increased beyond 2500 km. Hence, this study suggests that the human ankle has the capacity to be resilient to excessive loads during the extreme running distance. However, as only one study used T2* mapping on the tibiotalar cartilage over ultra-marathon, a further study may be required with more typical running distance (i.e., 5 km-20 km) including other joint cartilage such as subtalar joint, talocalcaneonavicular joint and calcaneocuboid joint.

Over long-distance running, the Achilles tendon seems to be altered. Achilles tendinopathy is a very frequent problem amongst elite runners [45]. It has been reported that runners who have trained more, covering longer distances tend to have more Achilles tendinopathy compared with less experienced and shorter distance runners [46]. Thickening of the Achilles tendon in the anteroposterior dimension is considered when diagnosing tendinosis using MRI. For healthy people, a range of 5.2 mm to 6 mm is generally considered a normal tendon size [45,47], whereas more than 6 mm is considered pathological [47]. The current selected study [33] reported that the diameter of Achilles tendon was already at an average of 6.8 mm at baseline, and it was significantly increased to an average of 7.8 mm over ultra-marathon. There would already be overloading even prior to the race, thereby explaining a larger Achilles tendon. This finding is in accordance with previous research [48], reporting that elite endurance runners generally have a larger cross-sectional area in the Achilles tendon than controls. However, when comparing race finishers with non-finishers, the plantar aponeurosis and subcutaneous edema were the only significantly different factors (not Achilles tendon properties). The authors [33] suggested that soft tissue edema might be more associated with abortion of the race than Achilles tendon properties.

Limitation

Meta-analysis could not be performed as all studies adopted different study populations, study designs, running types, and MRI grading systems. As none of the studies had a control group and/or second follow-up test following a rest period, and had small population numbers, it is difficult to know if any changes are clinically relevant.

All the selected studies adopted 1.5 T MRI, while 3.0 T MRI gives improved visualization of fine pathological features. In addition, there is a possibility that a relevant study has been omitted if a full-text was not written in English. One excluding German study [49] seems to be relevant our current review, reporting changes in retrocalcaneal bursa volume, the Achilles lesion volume and signal intensity of the calcaneus after a marathon. Some possible confounding factors were not reported: gender, age, background of lower limb injuries, occupational risks, family history of osteoarthritis and pre-existing malalignment should be considered for future studies. Furthermore, as the ultra-marathon represents an outlier in extreme sport, the findings related to this would be hard to generalise to a general running population.

Conclusion

The findings from this systematic review suggest that long-distance running may cause subtle changes in tarsal bones, metatarsal bones, tibiotalar cartilage, the Achilles tendon, subcutaneous and intraosseous in healthy adults. However, as very limited information is available with small participant numbers, variable study designs, and various population groups, it may difficult to interpret the findings and draw conclusions about whether long-distance running has a deleterious effect on the ankle and foot. Investigating the acute effect of a single long-distance running with more typical running distance on the ankle and foot is needed. As advanced T2/T2* mapping or T1p (rho) may detect more subtle and early changes and able to provide high signal-to-ratio with high resolution, these techniques would be ideal to examine the thin ankle cartilage.

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