Incidence of chronic knee lesions in long-distance runners based on training level: Findings at MRI
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Abstract

Purpose: The purpose of this study was to evaluate the incidence of chronic knee changes in long-distance runners based on the training status, including distance, running frequency, training pace, and running experience.

Methods: MRI of the knee was performed in 26 non-professional runners 5 days after their last training unit. Lesions of the menisci and cartilage (5-point scale), bone marrow and ligaments (3-point scale), and joint effusion were evaluated. A total score comprising all knee lesions in each runner was evaluated. The incidence of the knee changes was correlated with the training level, gender, and age of the runners.

Results: Grade 1 lesions of the menisci were found in six runners with a high training level, and in only four runners with a low training level. Grade 1 cartilage lesions were found in three high-trained runners and in one low-trained runner, and grade 2 lesions were found in one high-trained runner and in two low-trained runners, respectively. Grade 1 anterior cruciate ligament lesions were seen in three runners with a high- and in two runners with a low-training level. Runners with a higher training level showed a statistically significant higher score for all chronic knee lesions than those with a lower training level (p < 0.05).

Conclusions: MRI findings indicate that a higher training level in long-distance runners is a risk factor for chronic knee lesions.

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1. Introduction

Long-distance running has become a popular sport during the last several years, and the number of long-distance runners is increasing. Accordingly, the injury rate in runners, including acute injuries and overuse syndromes, has increased, especially in deconditioned or novice runners, and this has inspired several reports in the literature during these years [1–3].

However, different injury definitions used by the various authors of these studies make appropriate comparison of the study results difficult. In addition, study concepts about running distance and time span between MR examination and last training unit were divergent [4,5]. In epidemiologic studies, musculoskeletal injuries were subjectively defined only by the runners themselves, without using magnetic resonance imaging (MRI) as a correlate [1,2,6].

Among the modifiable risk factors for injury rate, weekly running distance is the strongest predictor of future injuries of the lower extremity [1,6]. Other training characteristics (speed, frequency, surface, duration) have little or no effect on musculoskeletal injuries.

A high level of sports activity, especially in sports with repetitive, high impact forces, has been considered a risk factor for chronic knee lesions that might result in osteoarthritis [7].

To our knowledge, there are few MR studies [8–10] that have evaluated the chronic impact of long-distance running on the musculoskeletal system, but none of these MR studies considered the training level of the runners.

The question prompting our investigation was whether there is a greater risk of chronic knee lesions in long-distance runners with a high training level.
2. Materials and methods

2.1. Study population

Twenty-six non-professional long-distance runners (19 men, seven women) with at least 10 years of running experience were recruited and screened to exclude subjects with a contraindication for MRI. Additional exclusion criteria were history of prior trauma, orthopedic surgery, and osteoarthritis. Informed written consent was obtained from all volunteers and the study protocol was performed with Institutional Review Board (IRB) approval.

Information on training distance per week, running frequency, average duration of training per year, and training pace was obtained. The training level was scored in two different grades: grade 1, the low training level, was defined as running frequency that did not exceed twice a week, with a running distance of less than 32 km per week, and a training period of more than 6 months per year, grade 2, the higher training level, was defined as running frequency more often than twice a week, with a running distance of more than 32 km per week, and a training period of more than 6 months per year. In addition, lesions of the knee were compared between runners with a faster and slower training pace (mean speed: 13.7 km/h versus 9.2 km/h). Gender and age of the runners were correlated with the knee changes. No training was performed during the last 5 days prior to the MR examination.

2.2. Subject demographics

Demographic data are summarized in Table 1. The average age of the 26 runners was 33 ± 5 years (range, 22–45 years), and the mean weight was 66.7 ± 9.1 kg (range, 53–92 kg). Body mass index was calculated by dividing weight in kilograms by the square of height in meters.

All runners had a normal body weight as defined by a body mass index between 18.5 and 24.9. Training distance varied between 12 and 90 km per week and the mean number of months of training per year was 4.5 ± 2.7 (range, 1–12 months).

<table>
<thead>
<tr>
<th>Sex (female/male)</th>
<th>Age (years)</th>
<th>BMI</th>
<th>Training distance (km)</th>
<th>Running frequency (per week)</th>
<th>Duration of training (months)</th>
<th>Training pace (km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>19/7</td>
<td>33 ± 5</td>
<td>21 ± 1.57</td>
<td>44.2 ± 11.8</td>
<td>2.7 ± 0.65</td>
<td>4.5 ± 2.7</td>
<td>10 ± 5 ± 3</td>
</tr>
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Note: numbers are indicated as mean ± S.E.M.

The training pace varied between 8.6 and 15 km/h.

2.3. MR data acquisition

MR imaging of the right knee of each runner was performed with a 1.5T MR scanner (1.5 Intera, Philips, Best, The Netherlands) and an extremity coil for the knee (Philips, Best, The Netherlands). During the MR examination, the knee was positioned in a standard position with a slight external rotation of approximately 20°.

Our standard protocol for knee examinations comprised the following pulse sequences: sagittal proton density-weighted sequence (TR 2618 ms, TE 15 ms, slice thickness 4 mm, slice gap of 0.30, matrix 512 × 512); sagittal T2-weighted turbo spin echo (TR 2618 ms, TE 100 ms, slice thickness 4 mm, slice gap of 0.30, matrix 256 × 256); coronal short Tau inversion recovery (STIR) (TR 1689 ms, TE 15 ms, TI 160 ms, slice thickness 3 mm, slice gap of 0.30, inversion time = 160 ms, matrix 512 × 512); sagittal fat-suppressed, three-dimensional, spoiled gradient-echo sequence (TR 20 ms, TE 7.827 ms, slice thickness 1.5 mm, no intersection gap, matrix 512 × 512); and axial T2-weighted turbo spin echo (TR 6140 ms, TE 100 ms, slice thickness 3 mm, slice gap of 0.30, matrix 512 × 512). The images were acquired with a field of view of 17 cm (proton density-weighted sequence, sagittal T2 turbo spin echo sequence) and 15 cm (all other sequences) [11–13].

2.4. Image analysis

MR images stored on a picture archiving and communication system (PACS) were analyzed on a PC-based PACS workstation (Agfa, Mortsel, Belgium) and evaluated in a cine mode. All patient and scan data were switched off during viewing. Two radiologists experienced in musculoskeletal MRI (5 years) and one dedicated musculoskeletal MRI specialist (10 years) interpreted the MR images. The two radiologists with 5 years of experience performed consensus reading, while the musculoskeletal MRI specialist performed single readings. The interobserver agreement between the musculoskeletal specialist and the two other radiologists was evaluated. In case of divergence, consensus reading was performed, with a majority decision providing the final result.

The anatomical structures of the knee joint including the menisci, cartilage, bone marrow, ligaments (comprising the anterior and posterior cruciate ligaments as well as the collateral complexes), and joint effusion were interpreted and scored for lesions.

Meniscal lesions were scored using a 5-point scale (grades 0–4). A grade 1 lesion was defined as punctate signal intensities not contiguous with an articular surface. A grade 2 lesion included linear intrameniscal intensity without articular surface extension. A grade 3 lesion was characterized by signal intensity that extended to one articular surface of the meniscus (meniscal tear). A grade 4 lesion had a signal intensity that...
reached the upper or lower surface of one meniscus (complex meniscal tear) [14–17].

A 5-point scale, ranging from 0 to 4, was used to score cartilage lesions on MR images according to the classification system of Outerbridge [18]. A grade 1 lesion was defined as irregular signal of the cartilage matrix but with an intact surface. A grade 2 lesion was defined as shallow superficial ulceration, fibrillation, or fissuring, involving less than 50% of the depth of the articular surface, whereas a grade 3 lesion indicated an involvement of 50% or more of the depth of the articular cartilage. A grade 4 lesion was defined by full-thickness chondral wear with exposure of subchondral bone.

For bone marrow edema and for ligaments, including the anterior and posterior cruciate ligaments and the medial and lateral collateral complexes, lesions were scored on a 3-point scale, ranging from 0 to 2. According to previous studies, bone marrow edema was scored as grade 1 if the extension of the hyperintensity seen on the STIR images was less than 10 mm in maximum diameter [19]. A grade 2 bone marrow lesion represented an extension of the hyperintensity of the bone marrow more than 10 mm in maximum diameter.

The ligaments were read as intact if the ligament could be shown as a homogenous low-signal-intensity structure with a continuous run from origin to insertion. Care was taken not to misinterpret normal fatty streaks within the ligaments as ligamental pathology. For ligamental lesions, we used a 3-point system from MR images, namely, intact, partial tear, and complete tear. Partial tear was defined by increased intraligamental signal alterations with preserved ligamental orientation. Complete ligamental tear was defined by discontinuity or nonvisualization of the ligament.

Joint effusion was differentiated on axial T2 and sagittal dual TSE between no effusion, only mild joint effusion, and fluid collections of more than 1 cm in sagittal diameter in the retropatellar bursa (Fig. 1).

In addition, other abnormalities, such as iliotibial band friction syndrome, and signal alterations or thickening of the patellar tendon, were recorded.

![Fig. 1](image-url) Axial T2-weighted images (TR 6140 ms, TE 100 ms) show the different grades of joint effusion in the retropatellar bursa: (a) no effusion; (b) mild effusion; and (c) major fluid collection >1 cm in the sagittal diameter.
2.5. Statistical analysis

Statistical analysis was performed using PC spreadsheet software (SPSS, version 11.5, Inc., Chicago, Ill., USA). A p-value <0.05 was considered significant.

The impact of training level and running speed on the incidence of knee lesions (total score of all knee lesions in each runner) was evaluated using the one-tailed Mann–Whitney U-test (a one-tailed test was chosen because it has been shown that osteoarthritis correlates with the intensity of sports activity and we assumed that other knee lesions might also show a positive correlation).

Demographic data and the total score were given as mean ± S.E.M. To rule out statistically significant differences in the incidence of knee lesions between male and female gender, the Mann–Whitney U-test was used. The correlations of age and knee lesions, as well as running speed and knee lesions were evaluated using the Pearson’s correlation. The normal distribution of data was evaluated using the Kolmogorov-Smirnov test.

The interobserver agreement on the MR readings was evaluated using the Pearson’s correlation. Agreement was defined as almost perfect, $\kappa > 0.8$; good, $\kappa = 0.8–0.61$; moderate, $\kappa = 0.6–0.41$; fair, $\kappa = 0.4–0.21$; or poor, $\kappa < 0.2$ [20].

3. Results

In our study population, 10 runners were characterized as high-trained and 16 runners were characterized as low-trained runners.

In all subjects, 10 meniscal lesions (grade 1), and six lesions (grade 2) out of 104 meniscal horns (four meniscal horns per runner), were found. Grade 1 lesions were seen in six high-trained runners and in four low-trained runners ($p = 0.63$). A grade 2 meniscal lesion was observed in three high- and three low-trained runners (Fig. 2). No grade 3 or 4 meniscal lesions were found. All signal alterations were seen in the posterior horn of the medial meniscus. Three of the runners who presented with a grade 2 meniscal lesion were temporarily symptomatic during and after running.

Three of the runners with a higher training level had a grade 1 lesion and one had a grade 2 lesion of the cartilage. In the group with the lower training level, one runner had a grade 1 lesion and two had a grade 2 lesion of the cartilage. Three of seven cartilage lesions were found in the patellar cartilage, four were found in the femoral cartilage, and none in the tibial cartilage.

Bone marrow edema less than 10 mm in diameter was present in one runner with a higher training level, and in one runner with a lower training level, respectively. In one of them, the changes in bone marrow were located subchondrally and adjacent to a cartilage lesion (Fig. 3). In three high-trained runners and in two low-trained runners, grade 1 lesions in the anterior cruciate ligament were noticed. These lesions were characterized by an increase in intraligamental signal with preserved orientation of the ligament. Grade 2 ligamental lesions were not detected. No signal alterations were noticed in the posterior cruciate ligament or in the collateral ligamental complexes.

Fig. 2. Sagittal proton density-weighted images (TR 2618 ms, TE 15 ms) of the medial meniscus of a runner. A small, central, hyperintense lesion (arrow) is observed in the posterior horn (type 1 lesion). The meniscal surfaces are intact.

Fig. 3. Coronal STIR images (TR 1689 ms, TE 15 ms, TI 160 ms) show a small area of high signal intensity in the bone marrow (lesion type 3) of the medial femoral condyle (arrow). The changes in the bone marrow are localized subchondrally, adjacent to a grade 2 cartilage lesion.
Joint effusions were present in eight high-trained and seven low-trained runners, and in one of the low-trained, the fluid collection was scored as large joint effusion. Degeneration of the patellar tendon with cystic transformation and effusion in the recessus infrapatellaris was noticed in one runner with a low training level. In two runners, bulging of the patellar tendon, with increased intratendinal signal, was observed.

The typical runner’s knee, characterized by the presence of the iliotibial band friction syndrome, was present in three of all runners. Increased fluid collection in the lateral compartment (Fig. 4) was detected [21]. These three runners complained about characteristic severe pain in the lateral compartment of the knee during running. The other runners did not suffer pain during training.

The total score, including all knee lesions in each runner, was $3.4 \pm 2$ in high-trained and $1.8 \pm 1.6$ in low-trained runners, respectively. The total score between the high-trained and low-trained runners differed statistically significantly ($p < 0.03$). There was no statistically significant difference in the total score between men and women ($p > 0.05$). Age did not correlate with the total score for knee lesions ($r = 0.019; p = 0.927$). The impact of running speed on the incidence of changes in the knee was evaluated by comparing the fast runners ($n = 10$) with the slow runners ($n = 16$). No correlations between running speed and lesions of the knee were found ($r = 0.166; p = 0.417$) (see Table 2). Meniscal lesions grade 1 were seen in five fast and in five slow runners, and grade 2 meniscal lesions were seen in two fast and in four slow runners (grade 1 lesions: 50% versus 31.2%; grade 2 lesions: 20% versus 25%). These differences were not statistically significant ($p = 0.776$).

The interobserver agreement on the MRI readings was 0.82 for menisci and 0.67 for cruciate ligaments, and the mean value was 0.71.

### Table 2

| Lesions of the knee in fast ($n = 10$) vs. slow runners ($n = 16$). Mean training pace was 13.7 km/h in fast and 9.2 km/h in slow runners |
|-----------------------------|---------------|---------------|---------------|
|                           | Grade 0 | Grade 1 | Grade 2 |
|                           | $n$   | $\%$   | $n$   | $\%$   | $n$   | $\%$   |
| Menisci                   |        |        |        |        |        |        |
| Fast                      | 3     | 30      | 5     | 50      | 2     | 20*    |
| Slow                      | 7     | 43.6    | 5     | 31.2    | 4     | 25*    |
| Cartilage                 |        |        |        |        |        |        |
| Fast                      | 7     | 70      | 2     | 20      | 1     | 10     |
| Slow                      | 12    | 75      | 2     | 12.5    | 2     | 12.5   |
| Bone marrow               |        |        |        |        |        |        |
| Fast                      | 9     | 90      | 1     | 10      | 0     | 0      |
| Slow                      | 15    | 88.9    | 1     | 6.2     | 0     | 0      |
| Cruciate ligaments        |        |        |        |        |        |        |
| Fast                      | 8     | 80      | 2     | 20      | 0     | 0      |
| Slow                      | 13    | 81.3    | 3     | 18.7    | 0     | 0      |

Comparison between slow and fast runners was not statistically significant ($p > 0.05$).

* Grades 3 and 4 meniscal lesions were not observed.

4. Discussion

Many studies have investigated the injury rate associated with running, reporting various rates between 25–65% [2,3,22,23]. In the literature, knee problems and injuries of the ankle, and foot are described as the most common injuries in both male and female runners [24,25].

In our study, with a special focus on the training level of the runners, we evaluated chronic injuries of the knee with MR imaging, which is an established excellent diagnostic tool for the imaging of soft tissue and joint lesions. A mileage of 32 km per week was chosen as a cut-off point for grading the training status in low and high training levels, because this distance is recommended in the literature for recreational runners to reduce sports-related injuries [1,6].

An additional risk factor for running-related injuries is a previous lower extremity injury [6,25,26]. In our study, we evaluated runners without a history of lower extremity injury to exclude this risk factor for a better comparability of the study population with regard to the pure training status.

Body mass index, which reportedly correlates with lesions of the musculoskeletal system [26,27], was in the normal range for all runners. Therefore, we assumed that the data obtained from our relatively homogeneous study population (patients in their early 30s) are conclusive for athletes of
normal weight. In contrast to other studies [28–30], age did not correlate with the total score of chronic knee lesions in our relatively young study population. It is postulated, that the incidence of degenerative meniscal lesions (grades 1 and 2) increases with advanced age.

The prevalence of meniscal tears in asymptomatic athletes did not differ significantly from the prevalence in the asymptomatic, age-comparable normal population (athletes: 9–20% versus non-athletes: 3–16%) [28–32].

The different findings on MR images revealed a good agreement for interobserver variability. In our study, slightly more lesions were seen in runners with a higher training level compared to a lower training level. These lesions presented subtle intrameniscal mucoid changes, indicating a chronic degeneration of the biochemical structure of the meniscus. The major tissue constituents of the meniscus, water, proteoglycan, and circumferential type I collagen fiber bundles, interact under repetitive increased external impact loading on the knee joint during long-distance running. The occurrence of transient intrameniscal lesions immediately after running has been described by other authors [5,10]. Therefore, in our study protocol, we required cessation of running for at least 5 days before the MR examination so as to avoid mistaking acute lesions for chronic lesions.

In our study, only few and mild cartilage lesions (grades 1 and 2) were observed. The lower number of cartilage lesions detected in our study compared to other studies [4,33] might be due to the fact that, on the one hand, we examined chronic changes and excluded transient lesions, and on the other hand, we used a 1.5 T MR imager (compared to 3 T). In accordance with a study that investigated the relation between low and moderate levels of physical activity and osteoarthritis, we found a higher percentage of slight chronic cartilage lesions in runners with a higher training level [34,35].

In contrast to other studies that found a higher prevalence of cartilage and meniscal lesions in males, our results showed no significant difference in the prevalence of chronic knee lesions between male and female gender [36,37]. This might be due to the fact that we investigated athletes with different training levels, whereas the other studies investigated an unselected population.

In the literature [22,23], bone marrow edema of the knees was seen in approximately 75–80% of runners [38,39]. In our study, only 7.7% showed bone marrow edema of the knees, whereas in one patient, the edema was located subchondrally, adjacent to a cartilage lesion and grade 2 meniscal lesion. Bone marrow edema is a transient lesion, which explains the higher percentage of bone marrow edema in runners who were examined immediately after exercise [39,40]. These observations were in accordance with the studies of Hohmann et al. [8], who stated that no increase in bone marrow edema was seen 24–48 h after a marathon.

Ligamental signal alterations were observed only in the anterior cruciate ligaments, whereas the posterior cruciate ligament and the collateral ligament complexes showed a homogeneous signal. The level of training had no impact on the changes in the ligaments. In accord with other studies [9,10,19], there were no incidences of severe lesions in the anterior cruciate ligament after a period of long-distance running. In our study, in three high-trained, and in two low-trained runners, slight ligamental signal alterations were found, indicating slight overuse of the anterior cruciate ligament without a history of trauma.

In our study, mild joint effusion was present in more than 50% of all runners with a low and a high training level, with no significant difference with regard to the training status. No severe pathology was seen in these knees to explain the presence of joint effusion. We think that the external impact loading on the knee during running causes mild joint effusion. It is hypothesized that joint effusions occur more frequently in less trained runners, which is likely attributable to a better adaptation by the knee joints to the repetitive external stress during running in well-trained runners. However, several studies show controversial results about the increase in fluid production caused by permanent friction of the joint surfaces due to greater mileage [5,8–10].

The knee joint is regarded as a closed musculoskeletal system with an interaction of all anatomic structures. Therefore, we believe that the total score of all knee lesions is a valid and useful tool to characterize the status of the knee. We observed that runners with a higher training level have a greater number of statistically significant knee lesions than low-trained runners, as evidenced by the total score. To evaluate the impact of the training pace on chronic knee lesions, we compared the fast runners with the slow runners, but could not find any correlation between running speed and chronic lesions of the knee. As previous studies have shown, sudden changes in running pace are one of the most frequent training errors and are related to a higher injury rate [41]. None of the runners in our study had a training pace slower than 6.4 km/h, which is supposed to protect against lower extremity injury [6,25].

The main limitation of this study is the lack of a baseline examination of the knee in runners before they gained running experience. In both groups, however, we excluded subjects with a history of previous injuries of the knee or orthopaedic surgery in order to exclude runners with pre-existing damage to the knee (e.g., ruptured menisci, osteoarthritis). With these strict inclusion criteria, we were able to detect lesions of the knee that had occurred due to running over years. Another major limitation is the lack of a control group consisting of non-athletes so as to compare our findings with the prevalence of knee lesions in the normal population. However, as a previous study has shown, there is no difference in the prevalence of knee lesions between athletes and non-athletes [28,29]. Another limitation is that factors such as biomechanical or structural abnormalities or personal running style, which may also play a role in the relation between training level and the risk of musculoskeletal injuries, were not evaluated in this study. Due to technical issues, we could not analyze the cartilage lesions with a special volume-rendering software program.
The findings of our MR study are in agreement with the results of other studies that have reported that the injury risk among runners significantly increases with increasing duration of running per week [25,34,35,38]. In these studies, the runners themselves defined the musculoskeletal injury by their subjective symptoms.

In conclusion, the results of our study show that the training level of runners in their early 30s with a normal body weight does affect the occurrence of mild chronic lesions of cartilage, ligaments, menisci, and bone marrow of the knee observed on MRI. Training pace has no impact on the incidence of chronic lesions of the knee.

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References