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What are causes and treatment strategies for patellar-tendinopathy in female runners?

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Abstract

Patellar-tendinopathy (PT) is a common overuse injury in long distance runners, especially in women. Until today, no definite combinations of clinical, biomechanical, or training variables, or causative factors in the development of PT have been found. This study focused on assessing the differences in biomechanical characteristics between healthy runners (CO) and runners with PT only. We examined a total of 42 women. 21 CO and 21 PT. 3D kinematics of barefoot running was used in the biomechanical setup. Both groups were matched with respect to height and weight. After determining dropouts due to forefoot running, poor quality of data and lack of matching subjects in CO in terms of body height and weight, the final population comprised 24 subjects ($\mathrm{CO} = 12$, $\mathrm{PT} = 12$). Biomechanical evaluations indicate eccentric overloading of the quadriceps muscle group (knee extensors), increased pronation velocity as well as a lack of joint coordination as major etiological factors in the development of PT. We assume that eccentric strengthening of the knee extensors, as well as reduction of pronation velocity through orthotics, proper running shoes, and balance training will help treat and possibly prevent PT.

Keywords: Patellar-tendinopathy; 3D Kinematic; Running; Overuse injury

1. Introduction

Although running has numerous positive effects on health, runners are prone to overuse injuries of the lower extremities (Hreljac et al., 2000), with the knee being one of the most common sites of injury (Taunton et al., 2002; Thomee et al., 1999; van Mechelen, 1992). The term anterior knee pain encompasses patellofemoral pain syndrome (PFPS) and patellar-tendinopathy (PT) (Thomee et al., 1999). Sports with jumping and explosive running are more commonly the cause of PT (Lian et al., 1996; Pierets et al., 1999; Stanish et al., 1985; Tibesku and Passler, 2005). Up to 5% of distance runners suffer from PT (Clement et al., 1981; Taunton et al., 2002).

The most important differential diagnosis for PT is PFPS. On occasion, the two conditions may both be present (Peers et al., 2005). The development of PT is assumed to be multi-factorial (Kannus, 1997). In addition to clinical and training variables (Allen et al., 1999; Devan et al., 2004; Pierets et al., 1999), anatomical (Kujala et al., 1986) and biomechanical abnormalities (Kannus, 1997) are considered to be predisposing factors for PT.

After summarizing several studies about sports injuries, Jozsa and Kannus, (1997) describe a higher incidence of tendon and other overuse injuries among women than among men.

There are many theories which attempt to explain the development of PT (Cook and Khan, 2001; Kannus, 1997; Peers and Lysens., 2005; Purdam et al., 2004; Stanish et al., 1985). However, no evidence based biomechanical causes or combinations of factors leading to the development of PT have been reported. This knowledge would be a starting point to efficiently treat PT in running. Therefore, the aim of the present study was to investigate differences between healthy female runners and female runners suffering from PT with regard to biomechanical characteristics in order to develop strategies to sufficiently treat or prevent PT.

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To accomplish this purpose, the following hypotheses were developed and addressed: There are differences in frontal plane kinematics, such as more adduction at the hip joint and more pronation at the subtalar joint in runners with PT compared to healthy runners. In sagittal plane kinematics, there is more flexion at the knee joint in runners with PT compared to healthy runners. Finally, a lack of coordination between subtalar and knee joint actions (Stergiou et al., 1999) is expected in runners with PT.

2. Materials and methods

2.1. Subjects

Healthy runners (control group, CO) and runners with PT were examined by the same investigating physician to ensure clinical relevance in the diagnosis of PT. Altogether, 21 patients with PT and 21 CO were selected as subjects for this study.

The study fulfilled all requirements of the Ethics Committee of the University of Tübingen (30/2004 V), including written informed consent of the subjects. Before analyzing the data, the subjects in the PT group and the control group were matched according to height and weight, since previous studies have shown that these gender-related variables can influence biomechanical results (Krauss, 2006). Nine subjects in the PT group were not included in the data analysis, because they were either forefoot runners (5 subjects), the 3D reconstruction of their kinematic data delivered poor results (2 subjects), or the matching partner in the control group was not adequate in terms of body height and weight (2 subjects). Ultimately, two groups of $n = 12$ each (CO: age 39 years, height 168 cm, weight 60 kg, BMI 21; PT: age 40 years, height 167 cm, weight 59 kg, BMI 21) were included in the data analysis.

2.2. Experimental procedures

2.2.1. Biomechanical measurement

Subjects ran barefoot in a laboratory setting on a 13 m EVA foam runway with a density of 100 kg/m^3. The particularly soft foam density was chosen to allow for natural and comfortable barefoot running. Running speed was pre-specified at 3.3 m/s (SD = 5%) and verified by two pairs of photo cells along the runway to enable a better comparison of the kinematic data. However, pre-specification of running speed was not critical for this study as anatomical differences were avoided by using the matching process and including only female runners. A minimum of 7 valid trials was recorded for each subject, so that 5 valid trials could be randomly selected for analysis. Trials were valid when speed was correct, subjects were rearfoot strikers, and each running trial was visually rated as being natural.

2.3. Kinematic measurements

All trials were recorded using a 6-camera 3D infrared system (ViconPeak, MCam M1, 250 Hz, Oxford). The marker set used in this study comprises a total of 18 spherical reflective markers, marking the pelvis (4th lumbar vertebra, 2 × ASIS), the thigh (greater trochanter, lateral and medial femoral condyle), the shank (tibial tuberosity, tibial crest, lateral and medial malleolus), and the foot (posterior calcaneus, medial and lateral calcaneus, navicular and cuniform bones, metatarsals 1, 2/3 and 5), constituting a four segment model. Three-dimensional joint motions were quantified by calculating Cardan angles (Cappozzo et al., 2005) using the program Bodybuilder 3.6 (ViconPeak, Oxford). Locating joint centers and joint axes was accomplished according to Isman and Inman (1969) for the talocrural and subtalar joints, and Bell et al. (1990) for the hip joint. Measurements were recorded one-sidedly; the affected leg in PT and a randomly selected leg in CO. The stance phase of the measured leg was normalized to 100 frames. The following angular displacements were calculated: hip flexion and extension, hip abduction and adduction, knee flexion and extension, internal and external tibial rotation, plantar flexion and dorsiflexion in the upper ankle joint, and eversion and inversion in the subtalar joint. Subsequently, discrete values (Maiwald et al., 2005; Stergiou et al., 1999) were examined for all joint angle excursions. Furthermore, the timing of maximum joint angle excursions, known as joint coordination, was calculated for both groups.

The dependent variables were:

- Maximum values (°) and timing of maximum values (% ROP) of hip flexion ($\mathrm{HFL}_{\max}$, t_{HFLmax}), hip adduction ($\mathrm{HAD}_{\max}$, t_{HADmax}), knee flexion ($\mathrm{KFL}_{\max}$, t_{KFLmax}), internal tibial rotation ($\mathrm{TIR}_{\max}$, t_{TIRmax}), ankle flexion ($\mathrm{AFL}_{\max}$, t_{AFLmax}) and ankle eversion ($\mathrm{AEV}_{\max}$, t_{AEVmax}) in CO and PT (Table 1).
- Range of motion values (°), maximum velocity values (°/s) and timing of maximum velocity values (% ROP) of sagittal hip motion ($\mathrm{HROM}_{\mathrm{FL/EX}}$, $\mathrm{HVEL}_{\mathrm{FL}}$, $\mathrm{tHVEL}_{\mathrm{FL}}$, $\mathrm{HVEL}_{\mathrm{EX}}$, $\mathrm{tHVEL}_{\mathrm{EX}}$) and frontal hip motion ($\mathrm{HROM}_{\mathrm{AD/AB}}$, $\mathrm{HVEL}_{\mathrm{AD}}$, $\mathrm{tHVEL}_{\mathrm{AD}}$, $\mathrm{HVEL}_{\mathrm{AB}}$, $\mathrm{tHVEL}_{\mathrm{AB}}$), sagittal knee motion ($\mathrm{KROM}_{\mathrm{FL/EX}}$, $\mathrm{KVEL}_{\mathrm{FL}}$, $\mathrm{tKVEL}_{\mathrm{FL}}$, $\mathrm{KVEL}_{\mathrm{EX}}$, $\mathrm{tKVEL}_{\mathrm{EX}}$), transverse tibial motion ($\mathrm{TROM}_{\mathrm{IR/ER}}$, $\mathrm{TVEL}_{\mathrm{IR}}$, $\mathrm{tTVEL}_{\mathrm{IR}}$, $\mathrm{TVEL}_{\mathrm{ER}}$, $\mathrm{tTVEL}_{\mathrm{ER}}$), sagittal ankle motion ($\mathrm{AROM}_{\mathrm{FL/EX}}$, $\mathrm{AVEL}_{\mathrm{FL}}$, $\mathrm{tAVEL}_{\mathrm{FL}}$, $\mathrm{AVEL}_{\mathrm{EX}}$, $\mathrm{tAVEL}_{\mathrm{EX}}$) and frontal ankle motion ($\mathrm{AROM}_{\mathrm{EV/IN}}$, $\mathrm{AVEL}_{\mathrm{EV}}$, $\mathrm{tAVEL}_{\mathrm{EV}}$, $\mathrm{AVEL}_{\mathrm{IN}}$, $\mathrm{tHVEL}_{\mathrm{IN}}$) in CO and PT (Table 2).

2.4. Statistical analysis

An independent t-test was used to examine the differences between CO and PT runners. The level of significance was set at $\alpha = .05$. To illustrate the practical relevance of the effects of possible biomechanical differences in terms of the measurement error, root mean square error (RMSE) was calculated for each individual quantity (Bland and Altman, 1996). Measurement differences larger than the RMSE value are considered to have practical relevance.

3. Results

3.1. Kinematic measurements

The PT group showed higher velocity in knee flexion and in ankle eversion compared to the healthy control group (Table 1). Furthermore, the timing of the maximal velocity was statistically significant earlier in knee flexion and in internal tibial rotation in runners with PT (Table 1). Finally, the maximum velocity in hip extension was significantly lower in PT compared to CO (Table 1). The absolute measurement differences between the groups were beyond the measurement error (RMSE) for the variables mentioned above.

Although the differences were not statistically significant, runners with PT showed a tendency towards more maximum adduction of the hip (Table 2). No statistically significant differences between PT and CO were found for the other variables (Table 2). Regarding the lower-extremity joint coupling pattern during running, PT showed earlier knee flexion, earlier internal tibia rotation and later hip adduction compared to CO (Table 2). The absolute measurement differences between groups were beyond the measurement error (RMSE) for the coupling variables.

Table 1
Range of motion values (°), maximum velocity values (°/s) and timing of maximum velocity values (% ROP) of sagittal hip motion ($\mathrm{HROM_{FL/EX}}$, $\mathrm{HVEL_{FL}}$, $\mathrm{tHVEL_{FL}}$, $\mathrm{HVEL_{EX}}$, $\mathrm{tHVEL_{EX}}$) and frontal hip motion ($\mathrm{HROM_{AD/AB}}$, $\mathrm{HVEL_{AD}}$, $\mathrm{tHVEL_{AD}}$, $\mathrm{HVEL_{AB}}$, $\mathrm{tHVEL_{AB}}$), sagittal knee motion ($\mathrm{KROM_{FL/EX}}$, $\mathrm{KVEL_{FL}}$, $\mathrm{tKVEL_{FL}}$, $\mathrm{KVEL_{EX}}$, $\mathrm{tKVEL_{EX}}$), transverse tibial motion ($\mathrm{TROM_{IR/ER}}$, $\mathrm{TVEL_{IR}}$, $\mathrm{tTVEL_{IR}}$, $\mathrm{TVEL_{ER}}$, $\mathrm{tTVEL_{ER}}$), sagittal ankle motion ($\mathrm{AROM_{FL/EX}}$, $\mathrm{AVEL_{FL}}$, $\mathrm{tAVEL_{FL}}$, $\mathrm{AVEL_{EX}}$, $\mathrm{tAVEL_{EX}}$) and frontal ankle motion ($\mathrm{AROM_{EV/IN}}$, $\mathrm{AVEL_{EV}}$, $\mathrm{tAVEL_{EV}}$, $\mathrm{AVEL_{IN}}$, $\mathrm{tHVEL_{IN}}$) in CO and PT

Group	$\mathrm{HROM_{FL/EX}}$ (°)	$\mathrm{HVEL_{FL}}$ (°/s)	$\mathrm{tHVEL_{FL}}$ (% ROP)	$\mathrm{HVEL_{EX}}$* (°/s)	$\mathrm{tHVEL_{EX}}$ (% ROP)	$\mathrm{HROM_{AD/AB}}$ (°/s)	$\mathrm{HVEL_{AD}}$ (°/s)	$\mathrm{tHVEL_{AD}}$ (% ROP)	$\mathrm{HVEL_{AB}}$ (°/s)	$\mathrm{tHVEL_{AB}}$ (% ROP)
CO	48±4	77±55	10±4	355±32	66±2	21±3	242±65	17±6	158±29	48±4
PT	48±5	106±92	10±4	326±28	63±3	19±3	23±88	21±7	177±39	48±3
Group	$\mathrm{KROM_{FL/EX}}$ (°)	$\mathrm{KVEL_{FL}}$* (°/s)	$\mathrm{tKVEL_{FL}}$* (%ROP)	$\mathrm{KVEL_{EX}}$ (°/s)	$\mathrm{tKVEL_{EX}}$ (%ROP)	$\mathrm{TROM_{IR/ER}}$ (°)	$\mathrm{TVEL_{IR}}$ (°/s)	$\mathrm{tTVEL_{IR}}$*** (%ROP)	$\mathrm{TVEL_{ER}}$ (°/s)	$\mathrm{tTVEL_{ER}}$ (%ROP)
CO	50±4	491±36	12±3	291±59	68±3	15±4	110±49	27±6	213±75	76±5
PT	50±4	533±35	8±4	277±59	70±3	12±3	102±60	12±8	175±42	76±7
Group	$\mathrm{AROM_{FL/EX}}$ (°)	$\mathrm{AVEL_{FL}}$ (°/s)	$\mathrm{tAVEL_{FL}}$ (%ROP)	$\mathrm{AVEL_{EX}}$ (°/s)	$\mathrm{tAVEL_{EX}}$ (%ROP)	$\mathrm{AROM_{EV/IN}}$ (°)	$\mathrm{AVEL_{EV}}$* (°/s)	$\mathrm{tAVEL_{EV}}$ (%ROP)	$\mathrm{AVEL_{IN}}$ (°/s)	$\mathrm{tAVEL_{IN}}$ (%ROP)
CO	75±5	310±33	11±3	772±115	81±3	42±4	234±51	11±4	501±64	81±4
PT	73±6	307±41	11±2	722±89	81±3	44±6	284±50	11±4	472±98	81±4

All mean values with standard deviations.
*$p<.05$, **$p<.01$, ***$p<.001$, $^{\dagger}p<.10$.

Table 2
Maximum values (°) and timing of maximum values (% ROP) of hip flexion ($\mathrm{HFL_{max}}$, t_{HFLmax}), hip adduction ($\mathrm{HAD_{ma}}$, t_{HADmax}), knee flexion ($\mathrm{KFL_{max}}$, t_{KFLmax}), internal tibial rotation ($\mathrm{TIR_{max}}$, t_{TIRmax}), ankle flexion ($\mathrm{AFL_{max}}$, t_{AFLmax}) and ankle eversion ($\mathrm{AEV_{max}}$, t_{AEVmax}) in CO and PT

Group	$\mathrm{HFL_{max}}$ (°)	$\mathrm{tHFL_{max}}$ (%ROP)	$\mathrm{HAD^{\dagger}_{max}}$ (°)	$\mathrm{tHAD_{max}}$* (%ROP)	$\mathrm{KFL_{max}}$ (°)	$\mathrm{tKFL_{max}}$* (%ROP)	$\mathrm{TIR_{max}}$ (°)	$\mathrm{tTIR_{max}}$* (%ROP)	$\mathrm{AFL_{max}}$ (°)	$\mathrm{tAFL_{max}}$ (%ROP)	$\mathrm{AEV_{max}}$ (°)	$\mathrm{tAEV_{max}}$ (%ROP)
CO	33±4	24±3	12±4	33±3	41±3	34±3	5±2	53±5	21±2	48±3	11±3	39±5
PT	31±6	22±3	15±3	36±3	41±6	30±3	4±2	47±5	21±2	47±4	14±2	37±5

All mean values with standard deviations.
*$p<.05$, **$p<.01$, ***$p<.001$, $^{\dagger}p<.10$.

4. Discussion

In the past, no evidence based biomechanical variables or combination of variables have been reported in the development of PT during running. Therefore, efficient treatment of PT in runners is still unclear. The aim of the present study was to investigate possible biomechanical differences in order to develop strategies to sufficiently treat or prevent PT.

Unexpectedly, and contrary to assumptions made in previous studies (Kannus, 1997; Taunton et al., 2002), the amount of pronation does not seem to play a role in the development of PT. Instead, pronation velocity is one of the etiological biomechanical key factors in runners with PT. As pronation is coupled with the internal rotation of the tibia (Stergiou et al., 1999), higher pronation velocity subsequently leads to an earlier maximum of internal tibial rotation and not necessarily to a higher amount of internal rotation, as seen in our study.

The importance of increased knee flexion velocity and decreased hip extension velocity as etiological biomechanical factors in PT was also unexpected, although the amount of flexion at the knee and extension at the hip do not seem to be important. This points to weak knee extensors, abdominal muscles, and back muscles during the eccentric touch down phase, and to weak hip extensors during concentric push-off (closed kinetic chain). Subsequently, maximum knee flexion during ground contact occurred earlier in runners with PT.

It seems that increased hip adduction during frontal plane movement could also be an etiological factor in the development of PT. If this is true, PT and PFPS would have similar etiological patterns in the frontal plane at the hip, since increased adduction of the hip, resulting in increased knee abduction moments, is described as a major risk factor in the etiology of PFPS (Stefanyshyn et al., 2006). This would explain why PFPS and PT sometimes coincide (Peers et al., 2005), and why typical symptoms of PFPS, such as pain or crepitation in the patellofemoral joint (Thomee et al., 1999), may also be present in patients with PT.

The timing of the joint angle curves seems to be different in the PT group compared to CO. The timing of the joint angles in PT is characterized by a delayed maximum of hip adduction and an early maximum of internal rotation of the tibia, relative to maximum knee flexion. If the differences in maximum joint excursion timing are accurate, this contradicts Tiberio (1987), who expects delayed maximum pronation in the development of knee problems, mainly in PFPS and PT.

Treatment strategies for PT should focus on reducing the loading of the knee extensors by eccentric strengthening. Furthermore, it seems appropriate to increase hip abduction strength to reduce pain in PT patients. Finally, the reduction of pronation velocity with customized orthotics (e.g. bowl shaped heel, medial wedge), intelligent running shoe design (e.g. crash-pad at the heel instead of dual density midsoles) as well as performing eccentric and concentric coordination exercises on balance pads could be beneficial for reducing pain. Moreover, all treatment strategies mentioned would automatically lead to an improvement in joint coupling in runners with PT.

Forefoot running appears to be a major factor in the development of PT, as almost a quarter of our initial subject population was forefoot runners. We assume that eccentric loadings of the knee extensors and/or increased hip adduction are also major causes of PT in forefoot running.

Our principal findings after comparing healthy female runners to female runners with PT show faster knee flexion, slower hip extension, increased pronation velocity, more hip adduction, as well as a lack of joint coordination in runners with PT. Future prospective studies should focus on treatment strategies, such as eccentric strengthening of knee extensors and reducing pronation velocity to ensure their effectiveness in reducing pain in runners with PT.

Conflict of interest

None of the authors have any financial or personal relationships with other people or organizations that could inappropriately influence or bias their work.

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References

Allen, G.M., Tauro, P.G., Ostlere, S.J., 1999. Proximal patellar tendinosis and abnormalities of patellar tracking. Skeletal Radiology 28, 220–223.

Bell, A.L., Pedersen, D.R., Brand, R.A., 1990. A comparison of the accuracy of several hip center location prediction methods. Journal of Biomechanics 23, 617–621.

Bland, J.M., Altman, D.G., 1996. Measurement error. British Medical Journal 313, 744.

Cappozzo, A., Della Croce, U., Leardini, A., Chiari, L., 2005. Human movement analysis using stereophotogrammetry. Part 1: theoretical background. Gait & Posture 21, 186–196.

Clement, D.B., Taunton, J.E., Smart, G.E., McNicol, K.L., 1981. A survey of overuse running injuries. Physician and Sports Medicine 9, 47–58.

Cook, J.L., Khan, K.M., 2001. What is the most appropriate treatment for patellar tendinopathy? British Journal of Sports Medicine 35, 291–294.

Devan, M.R., Pescatello, L.S., Faghri, P., Anderson, J., 2004. A prospective study of overuse knee injuries among female athletes with muscle imbalances and structural abnormalities. Journal of Athletic Training 39, 263–267.

Hreljac, A., Marshall, R.N., Hume, P.A., 2000. Evaluation of lower extremity overuse injury potential in runners. Medicine and Science in Sports and Exercise 32, 1635–1641.

Isman, R.E., Inman, V.T., 1969. Anthropometric studies of the human foot and ankle. Bulletin of Prosthetics Research 10, 97–129.

Jozsa, L., Kannus, P., 1997. Histopathological findings in spontaneous tendon ruptures. Scandinavian Journal of Medicine & Science in Sports 7, 113–118.

Kannus, P., 1997. Etiology and pathophysiology of chronic tendon disorders in sports. Scandinavian Journal of Medicine & Science in Sports 7, 78–85.

Krauss, I., 2006. Conceptional design of female-specific running shoes with respect to clinical, biomechanical, and anthropometrical gender differences. Unpublished Doctoral Dissertation, Eberhard-Karls-University of Tübingen, Tübingen.

Kujala, U.M., Osterman, K., Kvist, M., Aalto, T., Friberg, O., 1986. Factors predisposing to patellar chondropathy and patellar apicitis in athletes. International Orthopaedics 10, 195–200.

Lian, O., Holen, K.J., Engebretsen, L., Bahr, R., 1996. Relationship between symptoms of jumper's knee and the ultrasound characteristics of the patellar tendon among high level male volleyball players. Scandinavian Journal of Medicine & Science in Sports 6, 291–296.

Maiwald, C., Grau, S., Krauss, I., Mauch, M., Horstmann, T., 2005. Intra subject reliability of kinematic data in preferred and specified running speeds. In: Paper presented at the 7th Symposium on Footwear Biomechanics. ISB Technical Group on Footwear Biomechanics, Cleveland, OH, USA.

Peers, K.H., Lysens, R.J., 2005. Patellar tendinopathy in athletes: current diagnostic and therapeutic recommendations. Sports Medicine 35, 71–87.

Pierets, K., Verdonk, R., De Muynck, M., Lagast, J., 1999. Jumper's knee: postoperative assessment. A retrospective clinical study. Knee Surgery, Sports Traumatology, Arthroscopy 7, 239–242.

Purdam, C.R., Jonsson, P., Alfredson, H., Lorentzon, R., Cook, J.L., Khan, K.M., 2004. A pilot study of the eccentric decline squat in the management of painful chronic patellar tendinopathy. British Journal of Sports Medicine 38, 395–397.

Stanish, W.D., Curwin, S., Rubinovich, M., 1985. Tendinitis: the analysis and treatment for running. Clinical Sports Medicine 4, 593–609.

Stefanyshyn, D.J., Stergiou, P., Lun, V.M., Meeuwisse, W.H., Worobets, J.T., 2006. Knee angular impulse as a predictor of patellofemoral pain in runners. American Journal of Sports Medicine 34, 1844–1851.

Stergiou, N., Bates, B.T., James, S.L., 1999. Asynchrony between subtalar and knee joint function during running. Medicine and Science in Sports and Exercise 31, 1645–1655.

Taunton, J.E., Ryan, M.B., Clement, D.B., McKenzie, D.C., Lloyd-Smith, D.R., Zumbo, B.D., 2002. A retrospective case-control analysis of 2002 running injuries. British Journal of Sports Medicine 36, 95–101.

Thomee, R., Augustsson, J., Karlsson, J., 1999. Patellofemoral pain syndrome: a review of current issues. Sports Medicine 28, 245–262.

Tiberio, D., 1987. The effect of excessive subtalar joint pronation on patellofemoral mechanics: a theoretical model. Journal of Orthopaedic & Sports Physical Therapy 9, 161–165.

Tibesku, C.O., Passler, H.H., 2005. Jumper's knee—a review. Sportverletzung Sportschaden 19, 63–71.

van Mechelen, W., 1992. Running injuries. A review of the epidemiological literature. Sports Medicine 14, 320–335.