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REVIEW

Potential factors associated with knee pain in cyclists: a systematic review

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Video abstract

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Abstract: The potential factors associated with overuse injuries and pain in cyclists that are supported by evidence remain unclear. Our study aimed at assessing, using a systematic search of the most updated evidence, the main factors related to overuse knee-related pain and/or injuries in cyclists. The search assessed any potential mechanism related to knee pain or injury that could be used in the clinical practice. Databases were searched (i.e., PubMed, Scopus, Web of Science, and EBSCO). Studies were included if they presented results from original studies. They had to include, preferably but not limited to, recreational and/or competitive cyclists with or without knee pain. Quality of articles was assessed. Eleven articles were deemed eligible for full text appraisal. Studies involved generally the assessment of biomechanical outcomes associated with knee pain in cyclists. Overall, studies showed that cyclists with knee pain present larger knee adduction and larger ankle dorsiflexion and differences in activation for hamstrings and quadriceps muscles. Unclear results were observed for knee moments and no differences were observed for knee flexion angle, tibiofemoral and patellofemoral forces. It is important to state that varied types of knee pain were mixed in most studies, with 2 focused on anterior-related pain. Cyclists with overuse-related pain or injuries on their knees presented an increased medial projection of their knees and an altered activation of the Vastus Medialis and Vastus Lateralis muscles. However, this limited evidence is based on retrospective studies comparing cyclists with and without pain, which limits the conclusion on how cyclists develop knee pain and what are the main options for treatment of knee pain.

Keywords: injury, cycling, overuse, biomechanics

Introduction

Cycling is an appealing mode of locomotion and the adherence with cycling has increased progressively through the years. Due to the popularity of cycling and increase in pedaling time, injuries are very common in this sport. Although traumatic injuries are high in incidence in cyclists,[1,2] overuse injuries are more difficult to anticipate because of their multifactorial nature. The knee joint is one of the most affected body parts by overuse injuries.[1,2] Several epidemiological studies have shown that experiencing knee pain or knee injuries ranges between 14.8% and 33% in cyclists involved in long-duration pedaling.[3–9] Bakkes et al[4] presented a study where 902 cyclists were questioned at the end of the Burger-Sanlam 100/50 km race to identify injuries in the previous year. They found that 61% of cyclists did not have an injury in the previous year while 29% reported suffering from knee pain, suggesting that the long-duration cycling activity could have triggered their knee pain. Dannenberg et al[8] in a prospective study of 1638 recreational cyclists involved in the Cycle Across

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Maryland tour observed 76 overuse injuries, with the knee joint being the most affected body part for pain. Althunyan et al[3] showed that the prevalence of knee pain was 27.6% for amateur cyclists and 15.9% for professional cyclists, and they suggested that the type of bicycle could be an important factor in knee pain.

Different types of studies have been conducted to assess the possible reasons for pain and injuries due to cycling. For instance, the association with other sports activities,[3] bicycle misalignment,[4] inexperience or lack of pre-ride conditioning,[8] and long distances ride[10] were among the suggested triggers for knee pain. Dettori and Norvel,[11] discussed some possible mechanisms for non-traumatic injuries and prevention plan. As an example, for patellofemoral inflammation, the saddle could be too low and/or too far forward and most authors have encouraged to follow preventive adjustments, like proper saddle adjustment, the use of orthotics, cleat adjustment, and reduction in gear ratio (especially early in the season), among others.[1,2,12,13] However, only a few of these strategies have been tested experimentally, and most of the advocated recommendations lack of solid evidence that could be important in preventing injuries.

Sabeti-Aschraf et al[14] investigated 169 competitive mountain bikers and correlated their injury occurrence with the configuration of their bicycles. They found that 87 had overuse injuries after a race (Babenberger Trophy) and observed a significant correlation between inadequate saddle-pedal distance and knee pain ($p<0.04$). They concluded that bicycle adjustments have a direct impact on the incidence of overuse injuries in the competitive mountain bike cyclist. Conversely, Dahlquist et al[7] declared in their study that flexibility, strength, and bike fit measures did not predict injury and concluded that injury risk and prevention strategies need additional studies. There are a minimum of 20 review articles published suggesting how to prevent and treat knee pain and injuries despite lack evidence supporting the current advocated practices. With this in mind, the determinants of overuse injuries and pain in cyclists that are supported by evidence remain unclear.

Our study aimed to assess the potential factors associated with overuse knee-related pain and/or injuries in cyclists using a systematic search of the most updated evidence. The search intended to assess any potential mechanism related to knee pain or injury that could be used in the clinical practice. The findings from this search could then provide support for the assessment of key outcomes that could be used during clinical analysis of cyclists and/or bike fitting.

Materials and methods

Data search strategy

Databases were searched (i.e., PubMed, Scopus, Web of Science, and EBSCO) using the following keywords with Boolean operators: "knee", "injur*", "pain", "cycl*". Full details of articles were exported to EndNote (Thomson Reuters, New York, USA) to allow for exclusion of duplicates and assessment of articles' titles and abstract.

Inclusion and exclusion criteria

Studies were included if they presented results from original (i.e., experimental) studies, which resulted in the removal of review articles and epidemiological studies. Studies had to include, preferably, but not limited to, recreational and/or competitive cyclists with or without knee pain. We opted for including studies that did not assess cyclists with injury or pain on the knees but assessed injury-related outcomes that could potentially explain the reason for why cyclists have knee pain. The reason for this option was also an attempt to expand the understanding on what could trigger knee pain in cyclists (e.g., excessive compressive force at the patellofemoral joint). In addition to that was the potential reduced number of experimental studies assessing the determinants of knee pain in cyclists that sustained cycling as an exercise and/or training. However, due to the aim of our study, articles that assessed non-cyclists with knee injuries potentially not related to bicycle pedaling were removed. Studies that had focus on triathletes or any combined training mode were also excluded due to potential carryover effects from other training activities (e.g., swimming and running). Finally, articles that assessed traumatic (acute) injuries in cycling were also excluded.

Quality assessment

Quality of articles was assessed using a scale described by Agresta and Brown,[15] which comprised 16 elements (Table 1) worth 20 points in total. The items involved study design (worth 5 points), experimental control, study participants, methodology, and outcomes. Studies were then ranked as high (14–20 points), medium (7–13 points), and low quality (1–6 points). Articles were ranked simultaneously by both authors and disagreement was resolved to reach consensus.

Results

A total of 559 article titles were retrieved from the databases. Removal of duplicates resulted in 285 articles for assessment of title and abstract, which also led to the removal of 274

Table 1 Quality assessment of articles selected for appraisal in this systematic review

Methodological quality item	Bini and Hume,[18] (2014)	Bailey et al,[17] (2003)	Bini et al,[23] (2013)	Dieter et al,[19] (2014)	Farrell et al,[24] (2003)	Moore and Krabak,[21] (2007)	Priego Quesada et al,[26] (2017)	Swart et al,[22] (2008)	Wheeler et al,[20] (1995)	Gregersen et al,[25] (2006)
Study design criteria	4	4	2	4	4	1	2	1	4	2
Clear experimental controls used	–	–	–	–	0	0	–	0	–	–
Prospective study completed	0	0	0	0	0	0	0	0	0	0
Blinding of assessors and subjects used	0	0	0	0	0	0	0	0	0	0
Clear description of subjects/group	–	–	–	–	0	0	–	–	–	–
Balanced baselines between groups or stable across single subject	–	–	0	0	0	0	0	0	0	0
Target behaviors observable and measurable	–	–	–	–	–	–	–	–	–	–
Clear description of intervention methods	–	–	–	–	–	–	–	–	–	–
Attrition rate explained or minimal (<20%)	–	–	–	–	–	–	–	–	–	–
Clear description of observable or measurable outcomes	–	–	–	–	–	–	–	–	–	–
Statistical analysis described or conducted appropriately	–	–	–	–	0	0	–	0	–	–
Appropriate reliability methods described or used	0	0	0	0	0	0	0	0	0	0
Appropriate validity methods described or used	0	0	0	0	0	0	0	0	0	0
Clear conclusions drawn from results	–	–	–	–	–	–	–	–	–	–
Clear description of follow-up and maintenance outcomes	0	0	0	0	0	0	0	0	0	0
Total score	13	13	10	12	9	6	10	7	12	10

Notes: Quality of articles was assessed using a scale described by Agresta and Brown,[15] which comprises 16 elements worth 20 points in total.

articles not related to the aim of this study. The removal of articles from the assessment of titles and abstracts encompassed the inclusion/exclusion criteria for the study. Forty-one articles were then assessed and separated in 3 main categories. Twenty review articles were not assessed but will be referred in the "Discussion" section (i.e., review articles). Ten studies with focus on the epidemiology of overuse injuries were also separated to be discussed in terms of the incidence of injuries in cycling. Eleven articles were deemed eligible for full text appraisal but 1 was not assessed due to difficulties in retrieving the full text and the original language being German[16] (Figure 1). Results are presented in tables with information on sample size, study design, methods, outcomes, and main findings for each study.

Studies involved generally the assessment of biomechanical outcomes associated with knee pain in cyclists. Four studies[17–20] involved the assessment of cyclists (mostly recreational) reporting knee pain related to bicycle pedaling or providing medical evidence for knee pain (e.g., MRI). Two articles involved case studies of individual cyclists who had cycling-related knee pain.[21,22] One study[21] did not assess bicycle pedaling and was limited to clinical description of symptoms and imaging scan. Four studies[23–26] did not assess cyclists with injury or pain on the knees but assessed injury-related outcomes that could potentially explain the reason for why cyclists develop knee pain (Table 2).

Among the outcomes, authors reported kinematics (e.g., knee flexion angle), kinetics (e.g., knee joint moments), muscular activation (e.g., surface electromyography), and perceived comfort gathered from stationary cycling trials and others acquired from various tasks (e.g., isokinetic dynamometry).

Quality assessment indicated that only 1 study was ranked as low quality[22] while others were of medium quality. The main reason for the moderate quality of studies is related to the absence of a prospective design, lack of blinding for the assessors, lack of provision of reliability, and validity of the outcome measures, and no follow-up assessment being conducted. Therefore, the design of all studies was limited to cross-sectional retrospective (Table 1).

Overall, studies showed that cyclists with knee pain presented larger knee adduction and larger ankle dorsiflexion[17] and differences in activation for hamstrings and quadriceps muscles (Table 2).[19] Unclear results were observed for knee moments[20] and no differences were observed for knee flexion angle, tibiofemoral and patellofemoral forces.[18] It is important to state that varied types of knee pain were mixed in most studies, with 2 focusing on anterior-related pain.[17,19]

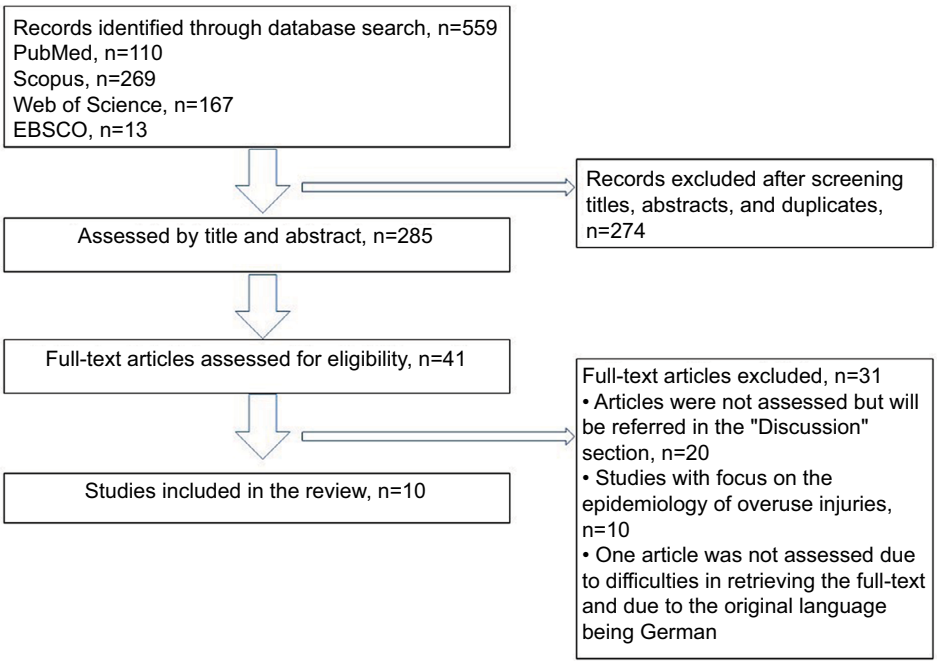

Figure 1 Flow diagram of the search methods used in this review.

Discussion

This systematic review of the literature intended to assess the potential factors associated with overuse knee injuries and knee pain in cyclists. After a careful search on the main databases related to health and sports sciences, we observed that there is limited evidence on the potential mechanisms related to overuse-related pain or injury. Surprisingly, 20 narrative reviews covering, but not limited to, knee pain in cycling were found, even though the evidence is scarce in terms of the determinants of overuse knee injuries, which limits the options for prevention and treatment.

Some differences were observed when comparing cyclists with and without knee pain. Cyclists with knee pain presented a medial projection of the lower limb during the power phase of cycling (from 12 to 6 o'clock positions of the crank) associated with an increased ankle dorsiflexion.[17] Although a larger medial projection of the femur in relation to the patella could lead to a reduced contact area for the patellofemoral joint,[27] this may be an adaptation to injury due to the retrospective nature of findings from Bailey et al.[17] The delayed offset of vastus lateralis and earlier offset of vastus medialis observed by Dieter et al[19] in cyclists with knee pain could also be a consequence from the medial projection of the femur. However, no data have been found in this issue when uninjured cyclists enforced a medial projection of their knees. In addition, no evidence on the control from hip adductors and/or abductors has been shown, which could help determining the rationale for the medial projection of the femur. In runners, a delayed onset of hip abductors has been associated with knee pain,[28] which provides a potential link between a delayed activation of hip abductors and the medial knee projection.

An alternative scenario would involve a differential activation of hip adductor (e.g., adductor magnus) and hip external rotators (e.g., gluteus maximus). This differential activation, in favor of the hip adductors, could lead to an enhanced medial projection of the knee. Bini et al[29] observed that an enforced hip adduction (commonly observed in time trial and track cycling) leads to an increased activation of hip adductors and larger forces applied to the pedals.[30] Interestingly, Ericson et al[31] observed that an enforced medial projection of the knees also leads to an increased lateral shear force at the knee joint, which could be expected to trigger knee injuries. However, no evidence has been provided on this link. Although the relationship between differential activation from hip muscles is lacking, clinicians could assess the ranges of motion and mobility for the hip joint of cyclists to evaluate whether changes in muscle force and mobility could be triggering the excessive medial projection of the knees.

Even though low saddle height has been previously related to increased knee loads (which could trigger knee pain and injury), cyclists with overuse-related pain did not present lower saddle heights or increased patellofemoral

Table 2 Summary of findings from studies selected for appraisal in this systematic review

Authors (year)	Sample size, participants with knee pain	Protocol	Outcomes	Main results
Bini and Hume,[18] (2014)	24 recreational cyclists, 8 with knee pain	Pedaling with 243±78 W at 90±2 rpm in 4 saddle heights (preferred, low, high, and optimum).	Knee flexion angles (3 and 6 o'clock), PFC, TFC, TFS forces	No differences between groups for any of the outcomes.
Bailey et al,[17] (2003)	24 cyclists, 10 with history of knee pain	Pedaling with 200±10 W at 90 rpm.	Knee flexion and adduction angles, ankle dorsi/plantar flexion, shank adduction velocity.	Larger knee adduction (1.9°) and larger dorsi flexion (4.9°) for cyclists with knee pain.
Bini et al,[23] (2013)	21 competitive cyclists, none with knee pain	Pedaling with 309±48 W at 90±2 rpm in three positions on the saddle (preferred, forward, backward).	Knee flexion angles (3 and 6 o'clock), PFC, TFC, TFS forces	Large increases in TFS force in the backward position compared to the preferred (19%) and forward (26%). Knee flexion angle increased at the forward compared to the backward saddle position (22%–36%). No change for other outcomes.
Dieter et al,[19] (2014)	17 cyclists, 7 with patellofemoral pain	Pedaling with RPE of 14 points (max 20) at 90 rpm. Work rate was not measured.	Amplitude, onset and offset of activation of vastus medialis, vastus lateralis, semitendinous and biceps femoris. Knee angles for onset and offset of muscles were determined.	Activation of biceps femoris was larger and Semitendinous was smaller for cyclists with pain. Delayed offset for vastus lateralis and biceps femoris and delayed onset for semitendinous were observed for cyclists with pain. Vastus medialis deactivates first in cyclists with pain, biceps femoris activates first in cyclists with pain, and semitendinous deactivates first in cyclists with pain.
Farrell et al,[24] (2003)	Ten athletes (non-cyclists) without knee pain	Pedaling with 280 W at 80–90 rpm.	Foot–pedal force (using shoe insoles) and knee flexion angle were measured.	Minimum knee angle of 33° was observed. The foot–pedal forces during cycling were only 18% of those occurring during running while the ITB is in the impingement zone (10°–30° of flexion).
Moore and Krabak,[21] (2007)	One cyclist with history of a right medial meniscectomy	No exercise undertaken.	MRI of the right knee.	Aneurysm of the popliteal artery, with posterior thrombus obstructing 50% of the lumen's diameter.
Priego Quesada et al,[26] (2017)	20 competitive cyclists without history of knee pain	Pedaling at 50% of maximal power output with 90±2 rpm at 3 saddle heights (eliciting a knee angle of 20°, 30°, and 40°) and 3 trunk flexion angles (35°, 45°, and 55°).	Perceived comfort, subjective fatigue perception and pain.	Saddle height eliciting a knee flexion angle of 30° was the most comfortable. Greater knee flexion had a negative effect on trunk comfort, accompanied by greater levels of fatigue and pain perception in the anterior part of the thigh and knee.
Swart et al,[22] (2008)	One 32-year-old male professional cyclist and former winner of the Tour de France with a 7-year history of recurrent anterior knee pain	1. Bilateral isokinetic testing: knee flexion-extension at 60 and 180°/s (concentric); hip adduction/abduction at 60°/s (concentric). Five repetitions at 60°/s and ten at 180°/s. 2. Pedaling at self-selected gear at 65, 75, 95, and 105 rpm. 3. MRI	From isokinetic: ROM, peak torque, flexors/extensors ratio, bilateral flexion deficit, bilateral extension deficit, rate of fatigue (from 10 repetitions at 180°/s). From pedaling, symmetry measure (bilateral balance in power output)	Low-grade patellar tendinopathy was observed from magnetic resonance. Increased eccentric knee flexion strength of the injured vs. uninjured leg (213.4 vs. 166.3 Nm). Mean power balance (51.0%±0.9%) was in favor of the injured leg, with larger values for lower cadences (i.e., 75 rpm –51.9%±1.5%).
Wheeler et al,[20] (1995)	34 cyclists, 7 with knee pain	Pedaling at 150, 250, and 350 W in preferred cadences (80–105 rpm) with toe-clips, clipless-fixed, and clipless-float.	Vertical moment applied to the pedal.	Internally applied peak moments increased with work rate. Peak moments were reduced when using clipless-float. Unclear results for pain.

(*Continued*)

Table 2 (*Continued*)

Authors (year)	Sample size, participants with knee pain	Protocol	Outcomes	Main results
Gregersen et al,[25] (2006)	15 cyclists without knee pain	Pedaling with 225 W at 90 rpm using 5 inversion/eversion foot angles (10° and 5° of inversion, neutral, 5° and 10° of eversion).	Three-dimensional knee moments (flexor/extensor, adductor/abductor, varus/valgus). Activation of vastus medialis and vastus lateralis.	The 10° everted angle reduced the peak varus moment by 55% in relation to the neutral while the 10° inverted angle increased the peak varus moment by 47% in relation to the neutral. Peak internal axial moment decreased by 53% of the neutral when the foot was 10° everted and increased by 88% of the neutral when the foot was 10° inverted. The axial moment was internal at the neutral position and decreased by 515% of the neutral becoming external for the 10° everted angle and increased by 389% of the neutral, becoming more internal for the 10° inverted angle. Vastus medialis activation increased relative to that of the vastus lateralis as the varus moment decreased.
Arnold et al,[16] (1988)*	104 cyclists, 24 with femoro-patellar pain and 28 with other knee symptoms	No exercise undertaken.	Extensibility of rectus femoris muscle.	Correlation reported between femoropatellar pain and reduced extensibility in rectus femoris muscle was observed.

Note: *When full text was unavailable.
Abbreviations: PFC, patellofemoral compressive; ROM, range of motion; RPE, rate of perceived exertion; rpm, revolutions per minute; TFC, tibiofemoral compressive; TFS, tibiofemoral shear.

forces than uninjured cyclists.[18] This result is in conflict with the theory that decreasing saddle height would lead to a larger compressive force at the patellofemoral joint.[1,2,12] However, data from Bini and Hume[18] are also retrospective in nature, which suggest that cyclists with knee pain may have sought for bike fitting advice or that the saddle height has limited influence in patellofemoral pressure. The pressure between the patella and the femur is dictated by muscle forces (which increases at low saddle heights) and by contact areas between cartilages (which also increases in larger knee flexions – that is, low saddle heights).[32] Therefore, there seems to be a plateau in patellofemoral pressure at saddle heights close to 100%±4% of the trochanteric height to the floor.[18] In addition, Wheeler et al[20] did not observe consistent differences in internal/external rotation moments at the tibiofemoral joint, which was initially anticipated to increase the stress in the knee joint soft tissues (e.g., meniscus). Although largely considered as a trigger of knee injuries, a limited "float" (i.e., rotation) of the cleat in relation to the pedal could not lead to overuse knee injuries. Theoretically, by increasing the "float" between the cleat and the pedal, the rotation moments could be reduced at the knee joint. However, a prospective link between increased float and reductions in knee pain is lacking.

Expanding the horizon of overuse (non-traumatic) injuries in cycling, Dettori and Norvel[11] indicated that only a few of the components of the bicycle could be associated to the likelihood of developing an overuse injury, none of them related to knee pain. Changes in saddle design and changing the inclination of the saddle (tilt) were tested as positive to reduce numbness at the perineum and low back pain, respectively. One of the potential reasons for the lack of association between bicycle configuration and knee pain is due to the distribution of forces among the various muscles of the lower limb.[33] Many studies observed that changes in saddle height, for example, have different responses in terms of changes in ankle, knee, and hip angles.[33] This has been hypothesized because the large number of muscles crossing the 3 main joints in the lower limb allow for innumerous combinations of activations and muscle forces. Therefore, cyclists riding with a low saddle height, for example, could change their ankle and/or hip angles (via changes in muscle activation and forces), which could then minimize the load transferred through the knee joint. This mechanism could then postpone the observed increases in knee loads only when opting for extremely low saddle heights.[34]

The rehabilitation of cyclists with knee pain or overuse injury requires a full understanding of the mechanism that

triggers the overuse injury. In the case of the knee joint, it is difficult to establish conclusive recommendations because only a couple of patterns have been observed to differ between injured and uninjured cyclists. The medial projection of the knee and the changes in activation for the quadriceps and hamstrings muscles could indicate 2 main options. The first would involve an assessment of force and mobility for hip adductors and abductors, which could provide evidence of potential imbalance of a given muscle group. However, we must keep in mind that this is very speculative given there is a lack of evidence in this area. The second option would involve the assessment of activation of vastus medialis in relation to vastus lateralis, which could help controlling the position of the patella in relation to the femur. Although patients with delayed onset of vastus medialis could be more prone to develop or sustain anterior knee pain, the literature is not conclusive in this area.[35] Therefore, treatment involving an enhanced activation of the vastus medialis should be a secondary option.

Limitations

This review was limited to some extent. The first limitation was the assessment of articles by authors from the same research group, which constrains the quality assessment to similar standards. An additional limitation was related to the quantity and quality of the studies. As previously discussed, no study used prospective designs to assess factors related to knee pain and injuries in cycling. Few studies included cyclists with existing knee pain or injury. Therefore, the conclusions of this systematic review are associated with the limitations of the evidence available. Future studies should be prospective in nature to understand the potential determinants of knee pain and injury in cyclists. The partition of the cohort by type of injury would then allow a more comprehensive understanding of how each component of the knee joint (e.g., patellofemoral) is affected by injury.

Conclusion

Cyclists with overuse-related pain or injuries in their knees present an increased medial projection of their knees and an altered activation of the vastus medialis and vastus lateralis muscles. However, this evidence is based on retrospective studies comparing cyclists with and without pain, which limits the conclusion on how cyclists develop knee pain and what are the main options for treatment of knee pain.

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Author contributions

All authors contributed toward data analysis, drafting and revising the paper and agree to be accountable for all aspects of the work.

Disclosure

The authors report no conflicts of interest in this work.

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