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SYSTEMATIC REVIEW

THE INFLUENCE OF EXTRINSIC FACTORS ON KNEE BIOMECHANICS DURING CYCLING: A SYSTEMATIC REVIEW OF THE LITERATURE

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ABSTRACT

Background: The knee is susceptible to injury during cycling due to the repetitive nature of the activity while generating torque on the pedal. Knee pain is the most common overuse related injury reported by cyclists, and intrinsic and extrinsic factors can contribute to the development of knee pain.

Purpose: Due to the potential for various knee injuries, this purpose of this systematic review of the literature was to determine the association between biomechanical factors and knee injury risk in cyclists.

Study Design: Systematic review of the literature

Methods: Literature searches were performed using CINAHL, Ovid, PubMed, Scopus and SPORTDiscus. Quality of studies was assessed using the Downs and Black Scale for non-randomized trials.

Results: Fourteen papers were identified that met inclusion and exclusion criteria. Only four studies included cyclists with knee pain. Studies were small with sample sizes ranging from 9-24 participants, and were of low to moderate quality. Biomechanical factors that may impact knee pain include cadence, power output, crank length, saddle fore/aft position, saddle height, and foot position. Changing these factors may lead to differing effects for cyclists who experience knee pain based on specific anatomical location.

Conclusion: Changes in cycling parameters or positioning on the bicycle can impact movement, forces, and muscle activity around the knee. While studies show differences across some of the extrinsic factors included in this review, there is a lack of direct association between parameters/positioning on the cycle and knee injury risk due to the limited studies examining cyclists with and without pain or injury. The results of this review can provide guidance to professionals treating cyclists with knee pain, but more research is needed.

Level of Evidence: 3a

Key Words: Biomechanics, cycling, knee injury, knee pain, overuse

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INTRODUCTION

With the increase in recreational and competitive cycling, cyclists are experiencing more overuse injuries related to repetitive loading.[1] Both intrinsic and extrinsic factors contribute to injury.[1] Intrinsic factors are inherent to the cyclist and include fitness level as well as anatomical alignment of the lower extremities.[1] Extrinsic factors are generally associated with factors external to the cyclist such as equipment, riding technique, and training.[1]

The knee is the most common joint impacted by cycling overuse injuries in recreational and professional cyclists.[1,2] Knee pain is reported to affect 40-60% of recreational cyclists and 36-62% of professional cyclists. [1,3,4] Anterior knee pain is the most common, which is likely due to patellofemoral pain, patellar tendinopathy, or quadriceps tendinopathy.[1,3-5] Factors that may cause anterior knee pain include increased pressure due to hill climbing, heavy workloads, increased training, altered patellar tracking, or by a combination of factors.[1,3,4] Many risk factors can contribute to the problem such as altered patellar position, decreased flexibility, increased quadriceps (Q) angle, muscle imbalances, and various limb torsional and foot deformities.[1,6] In a review article, Johnston reported that cycling cadence and workload impact moments around the knee, which may contribute to knee injury at higher effort levels.[7] Increasing knee flexion angle can increase forces impacting the knee[8] while co-contraction of the knee flexors and extensors can decrease them.[9] Thus the interaction of these variables as well as power output and cycling duration may be important in understanding cyclists who are at greater risk of injury due to loading.

Several knee structures are potentially at risk for overuse injury with cycling due to intrinsic and extrinsic factors. Patellofemoral pain (PFP) is one of the most common causes of knee pain in cyclists, resulting in anterior knee pain.[5] Female gender is a risk factor for PFP,[10] and PFP is more common in female cyclists.[11] An additional risk factor is reduced quadriceps strength,[10] which may cause the greatest prevalence of PFP during preseason training in cyclists.[4] Additional associated factors with PFP in cyclists include excessive varus knee moments during the power stroke,[12] excessive valgus knee alignment,[5] repetitive loading of the patella,[13] weak gluteal muscles,[5] increased Q angles,[11] excessive patellar lateral tilt,[5] and excessive foot pronation.[5] Patellar and quadriceps tendinopathies are additional causes of anterior knee pain in cyclists, [5] which are caused by chronic repetitive overload of tendons during quadriceps contractions.[14,15] Iliotibial band (ITB) syndrome is the most common cause of lateral knee pain in cyclists.[2] Proposed mechanisms for ITB syndrome are compression of fat beneath the ITB at the lateral femoral epicondyle or friction of the ITB as it moves across the lateral femoral epicondyle during repetitive knee flexion and extension.[2,11,16] When the knee reaches 20-30° of flexion, the ITB passes over the lateral femoral epicondyle,[17,18] creating an impingement zone for fat and an adventitial bursa.[2,5,11] ITB syndrome is likely caused by increased tibial internal rotation, ITB tightness, inward pointing of toes on the pedals, increased hip adduction, a bicycle saddle position that is too high, and rapid increase in mileage.[1,2,5,16,19] Medial knee injuries seen in cyclists include medial collateral ligament bursitis, plica syndrome, pes anserine syndrome and medial meniscus tear.[2] Plica syndrome is characterized by pain, snapping or clicking sensations as inflamed remnants of synovial tissue impinge against the anterior medial femoral condyle as the knee flexes and extends.[2,20] Medial meniscus tear is least likely to occur in cyclists, but can be symptomatic when rotating the leg to release the shoe from the pedal.[2] The posterior knee is the least commonly injured and may be attributed to biceps femoris tendinopathy presenting posterolaterally.[2] The etiology of biceps femoris tendinopathy is chronic overload of the hamstring muscles and tendons, and may be due to tight hamstrings or an excessively high saddle.[21]

Due to the potential for various knee injuries, this purpose of this systematic review of the literature was to determine the association between biomechanical factors and knee injury risk in cyclists. To accomplish this goal, biomechanical studies that examined extrinsic factors including kinematics, kinetics, and/or muscle activity under various cycling conditions and cycle component settings were included.

METHODS

Search Strategy: An initial literature search was performed in August of 2015 using CINAHL, Ovid, PubMed, Scopus & SPORTDiscus databases. Key terms used in the search included knee injuries, knee pain, cycling, cyclist, biomechanics, and overuse. All keywords were compiled and searched using AND/OR to further refine the search. Key words were used to screen titles that best addressed the research question. A second search using the same search terms and databases was performed in March of 2017 to locate additional articles published between August of 2015 and March of 2017.

Selection Criteria: Of the 46 articles selected, abstracts were screened based on the inclusion criteria of evaluating extrinsic biomechanical factors associated with the knee in cyclists. Studies were required to include measurement of one or more of the following at the knee during cycling: kinematics, kinetics, and muscle activity. Studies were excluded if they were not published in English, focused on injury in other areas of the body, or evaluated traumatic injury. The studies included were comparison or cross sectional.

Data Collection: Five reviewers evaluated the final studies after applying inclusion/exclusion criteria from full text articles. Each study was read and evaluated by two reviewers. Articles were graded using the Downs & Black scale for assessment of methodological quality and risk of bias.[22] The Downs & Black scale is considered a valid and reliable checklist for non-randomized studies and was deemed appropriate due to the observational nature of the studies.[22,23] Data extracted from articles included population, variables measured, results, and conclusions (Table 1).

RESULTS

Study Selection: Of the 72 studies found across the two searches, 14 were deemed eligible based on inclusion criteria (Figure 1). Studies were overall small with sample sizes ranging from 9-24 participants, with a total of 239 participants across studies.

Study Characteristics: Studies that reported gender included more male than female participants. Studies included adults aged 19 to over 50 years. Eleven studies were within-participant designs with one study including participants with knee pain[24] and 10 including participants without injury.[12,25-33] Three studies[34-36] compared participants with and without pain. Participants were described as competitive cyclists,[12,28,29] amateur cyclists,[32] experienced[24-26] or trained cyclists,[27] recreational cyclists,[30,31,34] non-cyclists,[33,36] or cyclists without further description.[35]

Assessment of Included Studies: Ten of the 14 studies had sample sizes of less than 20 participants. Downs and Black scores ranged from 3 to 13 (out of 27) with a median score of 10 (Table 1). Study quality was categorized according to percentage of the possible Downs and Black score as follows: low (≤ 33.3%), moderate (33.4% - 66.7%), and high quality (≥ 66.8%).[23] Therefore, the included studies were of low to moderate quality using this scale.[23] No blinding of assessors occurred in any comparison studies.

Methodology and Outcomes Measured: Methodology and outcomes measured varied across studies (Table 1). Knee kinematics with or without assessment of other joints were main outcomes assessed in 10 studies using 2D or 3D motion capture.[24,28-36] Knee kinematics were primarily measured in the sagittal plane, but three studies also measured kinematics in the coronal plane.[24,30,36] Knee kinetics with or without assessment of other joints were main outcome measures in 12 studies with different measures examined, including joint power,[25-27] muscle/joint moments,[12,27,29,30,34,36] patellofemoral compressive forces,[28,33,34] tibiofemoral compressive and shear forces,[28,33,34] pedal forces/pedal force effectiveness,[29,31,33,34,36] and crank torque.[32] Moments around the knee were primarily measured in the sagittal plane, but four studies also examined moments in the coronal plane.[12,24,30,36] Two studies measured muscle activity around the knee using electromyography (EMG),[12,35] and one study assessed pain.[36]

Experimental Conditions: Studies manipulated several conditions to examine effects at the knee, including cadence,[25,27,30] power output,[26,30,32] crank length,[25,27,32] saddle fore/aft position,[28] saddle height,[29,31,33,34] and foot position.[12,36] Participants used their own cycles mounted on a trainer,[24,28,35] a type of cycle ergometer,[12,25-27,29,30,32-34,36] or a standard cycle on a trainer.[31]

Cadence and Power Effects: Increasing cadence led to increased knee range of motion (ROM),[27] increased anterior and vertical pedal reaction forces,[30] and increased knee flexion moments.[30] As cycling power output increased, greater knee extension and

Table 1. *Study characteristics, results, and Downs and Black scores.*

Author, Year	DB Score	Subjects	Primary Variable(s)	Experimental Protocol	Results	Conclusions
Bailey et al., 2003	13	• 24 male cyclists • 10 with knee pain history • Experienced • 28.0+8.4 yrs	• Kinematics: coronal/ sagittal hip, knee, ankle	• Conditions: 90 rpm, 200±10W • Cycle: Own cycles on trainer	• Cyclists with knee pain had ↑ dorsiflexion & knee valgus. • No differences in knee flexion angle with & without knee pain. • Anterior knee pain seen when knee extensors active.	• More medial knee position (valgus) may disrupt knee extensor mechanism, leading to pain. • ↑ dorsiflexion with knee injury history possibly unrelated to pain as difference seen along with knee flexor moment.
Barrett et al., 2011	10	• 15 cyclists (12 male) • No injury • Experienced • 19-44 yrs	• Kinetics: 2D joint powers at hip, knee, ankle	• Conditions: 5 different crank lengths, 2 cadences (“optimized” & 120 rpm), 3sec maximal efforts. • Cycle: Isokinetic ergometer	• Crank length had no effects on power at optimized cadence. • At 120 rpm, crank length impacted hip & knee powers when comparing shortest & longest (150 & 190 mm) with ↑ at 150 mm.	• When cadence is accounted for, crank length does not impact joint powers.
Barrett et al., 2016	10	• 15 cyclists (12 male) • No injury • Trained • 19-44 yrs	• Kinetics: Sagittal plane forces, 2D muscle moments, joint powers at hip, knee, ankle	• Conditions: 5 different crank lengths, 2 cadences (“optimized” & 120 rpm), 3sec maximal efforts. • Cycle: Isokinetic ergometer	• ↑ Knee & hip ROM with ↑ cadence & crank length. • ↓ Knee extension moments & power and ↑ hip extension power with ↑ crank length.	• Powers most impacted by crank length.
Bini et al., 2013	9	• 21 male cyclists • No injury • Competitive • 28±7 yrs	• Kinematics: knee flexion • Kinetics (2D): Patellofemoral compressive & tibiofemoral compressive/ shear forces	• Conditions: 1 min; 90 rpm; max power output; preferred, forward and backward saddle positions (self-selected to simulate time trial or hill climbing). • Cycle: Own cycles on trainer	• ↓ Tibiofemoral anterior shear forces in forward saddle position. • ↑ Knee flexion angle comparing forward to backward saddle positions. • Neither position affected patellofemoral & tibiofemoral compressive forces.	• Tibiofemoral anterior shear forces more sensitive to knee angle. • Larger differences in knee flexion angle across conditions may be needed to affect compressive forces.
Bini et al., 2014	9	• 24 cyclists (12 road, 12 triathlon) • No injury • Competitive • 36±14 yrs (road), 42±8 yrs (tri)	• Kinematics: sagittal hip, knee, ankle • Kinetics (2D): pedal forces, net joint moments (hip, knee, ankle), pedal force effectiveness	• Conditions: Four 2min trials, submax effort, 4 saddle heights: 1) preferred, 2) low (-10° change in knee flexion angle at bottom dead center), 3) high (+10° change) 4) “optimal saddle height” (25° knee flexion). • Cycle: Stationary ergometer	• ↑ Force effectiveness optimal saddle height (road cyclists). • ↓ Ankle ROM & work at low saddle height (triathletes) • ↑Mean knee angles & ↓ mean hip angles at low & preferred compared to high & optimal saddle heights (all cyclists) • For triathletes, ↓ mean hip angle and ↑ hip ROM at preferred height compared to road cyclists.	• Road cyclists ↑effectiveness with saddle at optimal compared to preferred height; triathletes ↑ ankle work & ROM with saddle at optimal compared to low. • Optimal saddle position was up to 5% (road) -7% (triathlete) different from current saddle height.
Bini and Hume 2014	12	• 24 cyclists • 16 with knee pain) • Recreational • 40±11 yrs (pain group), 43±9 yrs (no pain group)	• Kinematics: sagittal hip, knee, ankle • Kinetics (2D): pedal forces, net joint moments (hip, knee, ankle), patellofemoral compressive & tibiofemoral compressive/ shear forces	• Conditions: Four 2min trials, submax effort, 4 saddle heights: 1) preferred, 2) low (-10° change in knee flexion angle at bottom dead center), 3) high (+10° change) 4) “optimal saddle height” (25° knee flexion). • Cycle: Stationary ergometer	• ↑ Anterior tibiofemoral peak forces at high and optimal compared to low saddle height • No differences in peak with and without knee pain across saddle conditions. • Large differences in knee angle with changing saddle heights.	• No differences seen in forces or kinematics with and without knee pain across saddle conditions. • Small sample size led to large within group variability.

Table 1. *Study characteristics, results, and Downs and Black scores. (continued)*

Dieter et al., 2014	10	• 17 cyclists • 10 without pain (4 male), 7 with PFPS (6 male) • 46±11.4 yrs, (pain group), 40±12 yrs (no pain group)	• Kinematics: knee flexion • EMG: quadriceps, hamstrings	• Conditions: 30s at the end of each of 10 mins, 90 rpm, RPE score 14. • Cycle: Own cycles on trainer	• No significant difference seen in onset of quadriceps muscles between groups. Vastus medialis turned off sooner with pain. • Significant difference in onset of hamstrings (biceps femoris contracted sooner than semitendinosus in pain group). • Cyclists with pain had ↓ activation of semitendinosus.	• Onset of quadriceps activity not correlated to pain. Differences in offset of quadriceps may not contribute to altered joint mechanics but may contribute to pain. • It is not known if the differences seen are causal or compensatory.
Elmer et al., 2011	12	• 11 male cyclists • No injury • Experienced • 19-44 yrs	• Kinetics: 2D joint powers at hip, knee, ankle	• Conditions: 5 power outputs (250-850W), 90 rpm, 3sec submax efforts plus 2 max effort at 90 and 110 rpm • Cycle: Isokinetic ergometer	• ↑ Absolute power at hip, knee, ankle as cycling power↑. • As power output ↑, relative knee flexion power ↑ & extension ↓. • Hip extension power dominant in producing power, but relative hip extension power unchanged with ↑ power output	• Joint powers ↑ with higher power output. • As intensity ↑, knee flexion power is more important. • Hip extension power is important; cyclists may benefit from hip extensor strengthening.
Fang et al., 2016	12	• 18 cyclists • No injury • Recreational • 55.8±11.0 yrs	• Kinematics: knee sagittal/coronal plane • Kinetics: knee sagittal/frontal plane moments	• Conditions. 2 mins, 8 conditions: 60 rpm, 5 workloads (0.5-2.5kg); 70, 80, 90 rpm at 1kg. • Cycle: Stationary ergometer	• ↑ workload led to ↑knee extension & abduction moments and ↑ knee vertical & medial pedal reaction forces. • ↑ cadence led to ↑ anterior & vertical pedal reaction forces and ↑ knee flexion moment.	• Differing effects of cadence and workload on knee forces.
Farrell et al., 2003	8	• 10 cyclists (6 male) • No injury • Recreational • 30.6±5.5 yrs	• Kinematics: knee flexion, crank angle • Kinetics: pedal forces	• Conditions: 80-90 rpm, 280W, five 4s trials of 5 min ride, saddle height to obtain 25-30° knee flexion at bottom dead center. • Cycle: Standard cycle on trainer	• Minimum cycling knee flexion was 30-35° due to ↑ lateral pelvic motion. • Peak pedal forces of 290.9±84.2 N at 110° of revolution. • Combined force & knee angle data showed that these cyclists not at risk for ITBS.	• Cyclists tested in these conditions are not at risk for ITB impingement. • Number of repetitions, anatomical differences, bike fit, & training may play more important roles in developing ITBS.
Ferrer-Roca et al., 2016	12	• 12 road cyclists • No injury • Amateur • 20.8±2.8 yrs	• Kinematics: 2D hip, knee, ankle • Kinetics: crank torque	• Conditions: 3 submax efforts; 150, 200, 250 W; 3 crank lengths (preferred ± 5mm). • Cycle: Stationary ergometer	• ↑crank length led to ↑torque and ↑hip and knee ROM.	• ↓ crank length may ↓ torque at knee.
Gardner et al., 2015	13	• 24 non-cyclists • 13 with knee OA, 11 without OA • 56.8±5.2 yrs (OA), 50.0±9.7 yrs (non-OA)	• Kinematics (3D): knee and ankle sagittal/coronal • Kinetics: Pedal reaction forces, 3D hip, knee, ankle sagittal/coronal moments • Pain: Visual analog scale	• Conditions: Last 30s of a 2 min effort; 60 rpm; 80W; foot in neutral rotation plus 2 toe-in positions • Cycle: Stationary ergometer	• 5° and 10° wedges↓ knee adduction angles • No ↓ seen in knee abduction moments or knee pain. • ↑ vertical pedal reaction forces.	• Results mixed as knee adduction angles ↓ without change in abduction moment or pain, while vertical loading ↑. • ↓ knee adduction angles may reduce overuse injuries

Table 1. *Study characteristics, results, and Downs and Black scores. (continued)*

Gregersen et al, 2006	3	• 15 cyclists • No injury • Competitive • 18-30 yrs	• Kinetics: Knee sagittal/ coronal moments • EMG: quadriceps, tensor fascia latae	• Conditions: 5 min effort, 90 rpm, 225W, 5 positions of ankle eversion/inversion • Cycle: Stationary ergometer	• ↑ Peak varus & average varus/valgus moments with inversion and ↓ with eversion. • Activation ratio of the vastus medialis to vastus lateralis ↑ with inversion	• Ankle eversion may prevent or ↓ patellofemoral pain.
Tamborin-deguy et al, 2011	10	• 9 male non-cyclists • No injury • 22-36 yrs	• Kinematics: knee sagittal plane • Kinetics (2D): pedal forces, tibiofemoral compressive/shear forces, & patellofemoral compressive force.	• Conditions: 1 minute, 70 rpm, 70W, 3 saddle heights (100, 103, 97% trochanteric height). • Cycle: Stationary ergometer	• No difference in peak tibiofemoral compressive/anterior shear components across heights. • ↑ knee flexion angle at lowest saddle height compared to other heights.	• Small changes in saddle height at low effort likely had little or no impact on joint loading. • Kinematic changes unrelated to forces in these conditions.

DB score = Downs and Black score; EMG=electromyography; ITB = iliotibial band; ITBS: iliotibial band syndrome; OA = osteoarthritis; PFPS=patellofemoral pain syndrome; ROM = range of motion; RPE; Rating of Perceived Exertion

abduction moments were seen.[30] Related to these increases, relative knee flexion power increased while extension decreased with increasing power output.[26] Interestingly, hip extension power was reported to be dominant in power production, but relative hip extension power did not change with increased power output.[26] Increased knee vertical and medial pedal reaction forces were seen with increasing power output.[30]

Bicycle Setting Effects: In two studies, Barratt et al. examined power[25,27] and muscle moments[27] at five different crank lengths at a cadence of 120 rpm and a cadence optimized to provide maximum power. They reported that crank length had no effect on power at joints, except for greater power at the shortest crank length of 150mm compared to the longest of 190mm at 120 rpm;[25] thus showing a combined effect of crank and cadence.[25] In another study, knee extension moments and power decreased, and hip extension power increased as crank length increased.[27] In contrast, Ferrer-Roca et al.[32] reported increased crank length led to increased torque around joints; however the range of crank lengths used was much smaller (10 mm)[32] than in Barratt et al. (40 mm).[25,27]

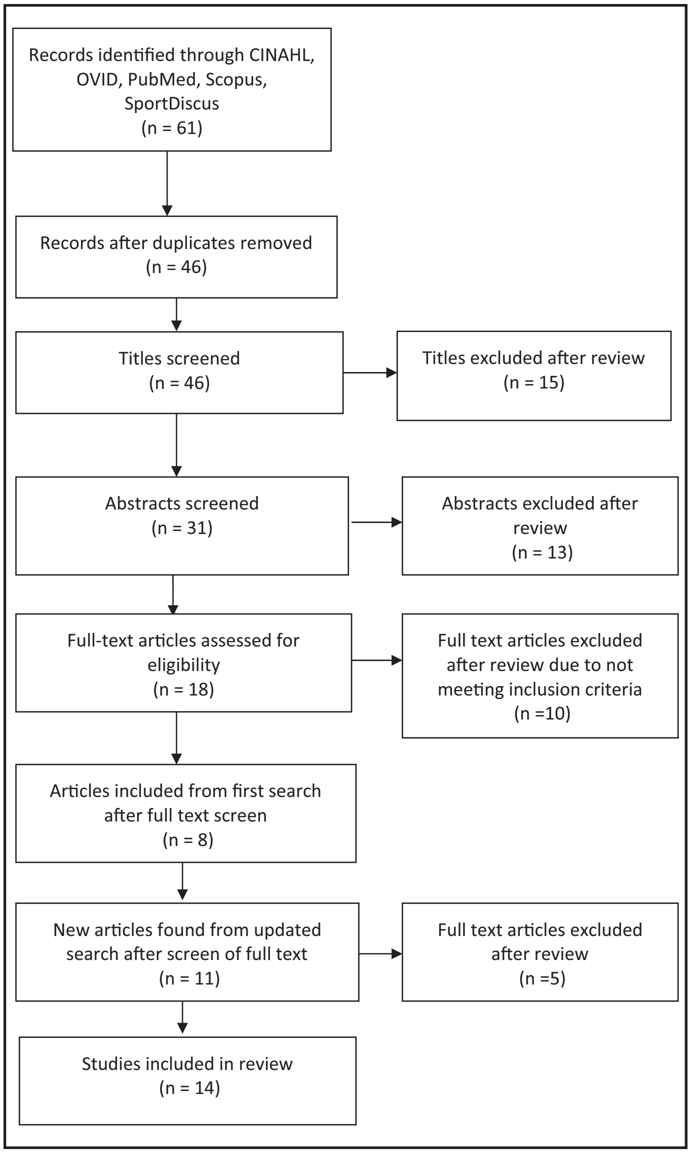

Figure 1. *PRISMA Flow Diagram.*

Bini et al.[28] manipulated saddle fore/aft position and reported increased knee flexion angles of 22-36% and decreased tibiofemoral anterior shear forces of 26% with the saddle at the most forward position compared to the most backward position. No differences were seen across positions in patellofemoral and tibiofemoral compressive forces.[28] Three studies examined various saddle heights,[29,33,34] one of which being a height considered optimal, which was defined as the position that achieved 25-30° of knee flexion at bottom dead center.[29] Bini et al.[34] examined four different saddle heights and found increased tibiofemoral anterior shear forces at high and optimal compared to low saddle height[34] and large differences in knee angle across conditions in recreational cyclists. There were no differences for patellofemoral or tibiofemoral compressive forces across seat heights and no differences seen between cyclists with and without knee pain.[34] In competitive cyclists, they found increased force effectiveness for road cyclists at optimal saddle height, and increased mean knee flexion angles at low and preferred compared to high and optimal saddle heights for road cyclists and triathletes.[29] Interestingly, Farrell et al.[31] reported that while saddle height was set in the optimal position statically, knee flexion seen while cycling was greater due to lateral movement of the pelvis in recreational cyclists, which may decrease risk of ITB impingement.[31] Finally, Tamborindeguy and Bini[33] set saddle height based on cyclists' anthropometrics and found no differences in peak tibiofemoral compressive/anterior shear components across three slightly different saddle heights based on percentages of floor-greater trochanter heights of 97%, 100%, and 103%.

Two studies examined effects of foot position on knee forces. For participants with osteoarthritis (OA) with and without pain, decreased knee adduction angles of 2.7° and 3.2° were seen with wedges placed to increase the toe-in angle by 5° and 10°, respectively; yet no changes were seen in knee abduction moments and vertical pedal reaction forces increased.[36] Ankle eversion of 10° was found to decrease knee peak varus moments by 55% and peak internal axial moments by 53% and to increase activation ratio of the vastus medialis to vastus lateralis (r = -0.23).[12] Thus eversion of the foot may decrease risks for PFP.[12]

Muscle Temporal Activation and Kinematics: Two studies compared temporal muscle activation patterns and kinematics between cyclists with and without pain without manipulating cycling conditions. Dieter et al.[35] reported differences in muscle activity patterns for cyclists with and without PFP. In cyclists with PFP, offset of the vastus medialis occurred 22 ± 23 ms sooner than the vastus lateralis, onset of the biceps femoris occurred 111 ± 78 ms sooner than the semitendinosus, and the semitendinosus had overall decreased activation compared to cyclists without pain.[35] Bailey et al.[24] reported differences in knee and ankle angular positions between cyclists with a history of anterior knee pain or patellar tendinitis and uninjured cyclists. The previously injured group had lower peak knee adduction angles and increased ankle dorsiflexion angles. No differences were found for peak knee flexion angles.[24]

DISCUSSION

Cycling parameters (i.e., cadence and power output) and bicycle fit settings have differing effects on kinematics, kinetics, and muscle activity around the knee. Few studies compared cyclists with and without knee pain, so injury risk can only be surmised based on the results of biomechanical studies that examine cyclists without injury or pain. There is also a lack of longitudinal studies to assess the effects of altering parameters on knee injury and pain. Thus, causation cannot be determined.

Studies examining cycling kinetics indicate that various stresses are imparted on the knee based on a variety of kinetic variables. Vertical and anterior pedal reaction forces increase at higher cadences,[30] and vertical and medial pedal reaction forces increase at higher power outputs.[30] Tibiofemoral peak anterior shear forces were found to be increased at higher saddle heights,[34] and ankle inversion increased peak vertical forces.[12] These findings are in partial agreement with an earlier study by Ericson and Nisell,[37] which reported that higher saddle heights significantly increased tibiofemoral anterior shear forces, but decreased tibiofemoral compressive forces. The findings of the studies in this systematic review and earlier studies have implications for loading of the knee joint during cycling and suggest that lower cadences, lower workloads, a higher saddle height, and foot eversion might be preferred for cyclists with knee pain due to tibiofemoral compressive joint loading, such as with medial tibiofemoral OA. In contrast, cyclists with anterior cruciate ligament injury or reconstruction may benefit from a lower saddle height and lower cadences.[30,34,37] However, force effectiveness, a measure of force output in relation to angle of force application, may be decreased with these settings,[29] and thus the effects of combining these conditions is unknown. The effect of crank length due to loading is more difficult to interpret as a shorter crank length at a higher cadence increases power output,[25] yet increased crank lengths may shift more of the power production from the knee extensors to the hip extensors.[27] When comparing the moments around the knee to other activities such as walking, jogging, and stair climbing, the extension and flexion moments are generally smaller when cycling at 120 Watts. At 240 Watts, the loads were similar to the other activities.[38] Knee injuries are the most commonly reported injuries in cyclists, thus it may be the combined effects of workload, cadence, and positioning on the cycle that contribute to injury.

Shear forces are another concern in cyclists, particularly possible injury to the anterior cruciate ligament (ACL) or after an ACL reconstruction. Tibiofemoral anterior shear forces may decrease with a more forward[28] or lower saddle position,[34] decreasing potential strain on the ACL. However, studies reported low in vivo ACL strain[39] and low anterior tibiofemoral shear force[37] during cycling. Fleming et al.[39] reported that strain on the ACL during cycling was approximately 1.7%, and did not change significantly with alteration of cadence or power level. Strain on the ACL during cycling was low compared to 3.6% while squatting and 2.8% while extending the knee from flexion.[39] Strong contraction of the hamstrings during the second half of the power phase may minimize ACL strain.[40] Posterior pull of the hamstrings on the tibia when the crank angle is 180° from top dead center may limit ACL strain as the knee approaches its least flexed position of 37°,[41] an angle which is within the range of greatest ACL strain during activities, 0° - 50° flexion.[42] While shear forces on the ACL during cycling appear to be low, more research is needed to examine shear forces on the posterior cruciate ligament and patella during cycling. Thus, cyclists with anterior cruciate ligament injury or reconstruction may benefit from a lower saddle height or more forward saddle position.[28,34] as well as a lower cadence.[30]

Medial and lateral regions of the knee are also susceptible to injury. Coronal plane forces are affected by foot position, with eversion lowering peak varus and internal axial moments and increasing vastus medialis activation compared to inversion.[12] For people with medial knee OA, rotating the shank to increase toe-in angle reduced peak knee adduction angles, with no impact on peak knee abduction moments.[36] Gardner et al.[36] hypothesized that an alignment change with increased toe-in foot position would decrease the frontal plane moment arm of the pedal reaction force, which would decrease knee abduction moments. As competitive cyclists and people with knee OA differ in knee alignment, findings may be specific to these populations. One study examined the impact of saddle height on ITB syndrome and reported that a lower saddle height that increased minimum knee flexion angle to greater than 30° kept the ITB out of the impingement zone.[31] For cyclists at risk for ITB pain, a lower seat height may also be desirable by reducing compensatory lateral pelvic motion[31] that can increase stress to the ITB. Overall, more research is needed to better understand the effects of cycling on the medial and lateral regions of the knee.

Few studies have examined PFP in cyclists specifically, which is surprising due to the prevalence of anterior knee pain in cyclists.[2] One study reported differences in muscle activation between cyclists with and without PFP.[35] Although no differences were found between groups for vastus medialis onset times, the slower contraction offset time of vastus lateralis relative to vastus medialis in the PFP cyclist group may be associated with lateral patellar maltracking.[35] These findings are consistent with a systematic review that did not find a difference in vastus medialis and vastus lateralis contraction onset in persons with PFP, but reported significant variability in muscle activation ratio.[43] Dieter et al.[35] also reported earlier contraction onset and later offset time of the biceps femoris relative to the semitendinosus in the PFP group compared to controls.[35] These changes may result in increased tibial external rotation, with a resultant increase in the dynamic Q angle and potentially increased lateral patellofemoral joint stress.[44,45] As the hamstrings are active longer than the quadriceps during cycling,[21] altered hamstring activation may be more critical to development of PFP in cyclists compared to vasti activation. However, it is unknown if altered muscle activation is compensatory to or a cause of PFP. Altered coronal plane knee position may be associated with PFP as reduced knee adduction angles, that is, a more valgus position, are seen in cyclists with anterior knee pain or patellar tendonitis.[24] Studies in this systematic review that examined the impact of saddle position on patellofemoral compressive forces did not find significant differences.[28,33] In contrast, an earlier study by Ericson and Nisell[8] reported that a lower saddle increased patellofemoral joint compressive forces. Although increased knee flexion from a lower saddle position would increase patellofemoral joint reaction force,[46] patellofemoral joint cartilage stress does not increase linearly with increasing knee flexion from 0° to 90°.[47] Patellofemoral joint stress increases to a lesser degree than patellofemoral joint reaction force with increasing knee flexion due to increased patellofemoral joint contact surface area.[47] Tamborindeguy and Bini[33] found the highest patellofemoral compressive force occurred with the knee at approximately 75°-80°. Thus, patellofemoral joint stress may be minimized during cycling by greater patellofemoral joint contact area at knee joint positions which have high patellofemoral joint reaction forces.[47] PFP in cyclists may not be related to high joint stress, but rather secondary to frequent patellofemoral joint loading from repetitive knee extension. This repetitive loading could cause supraphysiologic loading of osseous and non-osseous structures potentially causing loss of tissue homeostasis and PFP.[48,49] More research is needed to understand patellofemoral compressive and shear forces and how they are associated with risk of injury.

In the articles in this systemic review, no issues specific to the posterior knee were discussed. Elmer et al.[26] reported that knee flexion power increased relative to extension power as overall power output increased,[26] which may have implications for biceps femoris tendinopathy.[2] Interestingly, Dieter et al.[35] found that biceps femoris muscle activation occurred prior to semitendinosus onset in cyclists with PFP, unlike those without this anterior pain condition. More research is needed on posterior knee pain in cyclists.

There are several limitations of this systematic review. Studies differed considerably in methodology, making qualitative or quantitative comparisons challenging. It is also difficult to make strong recommendations as far as the amount of change needed to decrease injury risk as studies vary in the magnitude of changes in cycling parameters and bicycle settings. Bini et al.[34] reported that even a 5% difference in saddle height can affect knee joint kinematics by 35% and joint moments by 16%;[34] yet it is unknown how these differences then translate into injury risk. There is also the lack of direct association between parameters/positioning on the cycle and injury due to limited studies examining cyclists with and without pain or injury and a lack of longitudinal studies. More research is needed to establish clear links and recommendations by manipulating parameters based on the available literature and knowledge of biomechanics impacting specific areas of the knee. Longer term effects on pain, performance, and participation should then be assessed. Another limitation is the inclusion of 2D measurements in some studies. 2D data capture can be misleading as movement outside of the sagittal plane impacts how each joint is visualized on a 2D image. In addition, 3D kinetic measurements are needed to fully understand the effects on the knee in all three planes.

CONCLUSIONS

The results of this systematic review indicate that changes in cycling parameters or positioning on the bicycle can impact movement, forces, and muscle activity around the knee. While studies showed differences across some of the extrinsic factors, there is a lack of direct association between parameters/positioning on the cycle and knee injury. Despite the lack of this clear association, the results of this systematic review can provide guidance to professionals treating cyclists with knee pain. The literature provides important information about how biomechanical factors and positioning on the bicycle can increase or decrease stress in specific areas of the knee joint. Further research is needed with larger samples of cyclists with including those without knee pain to better understand direct relationships between these variables and knee pain during cycling.

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