

Biomechanical analysis of knee flexion and saddle height adjustment on knee pain in amateur cyclists

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Abstract:

Introduction: Cycling is increasingly popular worldwide owing to its health, transportation, and environmental benefits. However, overuse injuries are common, with the knee being the most frequently affected joint. Among these, anterior knee pain—often related to excessive knee flexion at bottom dead center—is particularly prevalent in amateur cyclists. Proper bicycle fitting, especially saddle height adjustment, has been suggested as a preventive measure, yet few studies have examined its short- and medium-term effects on pain reduction. This study investigated the relationship between knee flexion angle and the impact of saddle adjustment on knee pain in amateur cyclists. **Materials and Methods:** A longitudinal, quantitative, correlational study was performed with 38 male amateur road and mountain bike cyclists aged 25–57 years. Participants were divided into two groups according to knee flexion angle: $>40^\circ$ ($n = 21$) and $<40^\circ$ ($n = 17$). Knee pain was evaluated using a Visual Analog Scale (VAS) at three time points: before adjustment, immediately after saddle fitting, and two weeks after adjustment. Sagittal plane kinematics were analyzed through video recordings with reflective markers using Kinovea software. Statistical analyses included t-tests, ANOVA with Tukey post-hoc comparisons, and Spearman's correlation, with significance set at $p < 0.05$. **Results:** Cyclists with knee flexion $>40^\circ$ reported significantly higher pain than those with $<40^\circ$ (VAS 4.4 ± 1.9 vs. 0.9 ± 1.5 , respectively, $p < 0.001$). Following saddle adjustment, flexion angles decreased to 25° – 30° , accompanied by significant pain reduction both immediately (VAS 2.7 ± 1.4) and after two weeks (VAS 1.4 ± 1.6). A strong correlation was found between knee flexion angle and pain before adjustment ($r = 0.72$), which disappeared after bike fitting. No significant changes were observed in the $<40^\circ$ group. **Discussion:** The findings confirm that excessive knee flexion ($>40^\circ$) is strongly associated with greater pain perception in cyclists, likely owing to increased patellofemoral compressive forces and altered tendon mechanics. Saddle fitting proved effective in reducing pain and optimizing knee biomechanics, aligning with previous studies that recommend a bottom dead center flexion angle of 25° – 30° . **Conclusions:** Knee flexion angle is a key determinant of knee pain in amateur cyclists. Angles exceeding 40° increase the risk of discomfort, whereas saddle height adjustments that achieve a flexion angle of 25° – 30° significantly reduce pain both immediately and over time. Therefore, proper bike fitting should be considered an essential preventive and therapeutic strategy to minimize overuse-related knee injuries in cyclists. **Keywords:** Patellofemoral biomechanics, Overuse injury prevention, Cycling kinematics, Saddle ergonomics, 2D motion analysis

Introduction

Cycling participation has increased significantly worldwide in recent years owing to its well-established health, transportation, and environmental benefits (Kotler et al., 2016; Maizlish et al., 2017). As a low-impact endurance activity, cycling improves cardiovascular fitness and muscular endurance while also serving as a sustainable mode of commuting. Despite these advantages, cycling is associated with a high prevalence of overuse injuries. Epidemiological studies indicate that between 50% and 90% of cyclists experience such injuries, depending on the population and cycling modality, with the knee being the most commonly affected joint (Bini & Hunter, 2023; Lebec et al., 2014). Among these, anterior knee pain is consistently reported as the most frequent musculoskeletal complaint in both amateur and professional cyclists, with prevalence estimates ranging from 40% to 63% (Bini & Hunter, 2023; Piotrowska et al., 2017).

Knee pain in cyclists most commonly presents as patellofemoral pain syndrome, patellar tendinopathy, or iliotibial band syndrome (Dettori & Norvell, 2006). These conditions are primarily non-traumatic in nature and are strongly influenced by training load, anatomical predispositions, and improper bicycle fitting (Menard et al., 2020; Priego Quesada et al., 2019). Among fitting variables, saddle height has been identified as a critical risk factor for patellofemoral pain because it changes lower-limb kinematics and increases compressive forces on the knee joint (Priego Quesada et al., 2017; Scoz et al., 2021; Vigário et al., 2024). A saddle positioned too low

results in excessive knee flexion, whereas a saddle positioned too high promotes overextension; both scenarios negatively impact comfort, pedaling efficiency, and joint health.

Beyond injury prevention, a cyclist's position on the bike greatly influences performance (Malizia & Blocken, 2021; Husband et al., 2024), comfort (Ayachi et al., 2015), and injury risk (Bini & Priego-Quesada, 2022). Therefore, the impact of bike configuration has been extensively studied, with bike fitting recognized as a primary strategy to optimize efficiency, comfort, and safety. This process entails adjusting the foot–shoe–pedal, pelvis–saddle, and hand–handlebar interfaces to match the cyclist's individual characteristics and the specific demands of the cycling discipline (Millour et al., 2023).

Recent evidence shows that suboptimal saddle height is associated not only with knee pain but also with increased joint loading, higher oxygen consumption, and reduced pedaling economy primarily owing to changes in joint angular motion and the force–length–velocity relationships of muscles (Bini & Priego-Quesada, 2022; Connick & Li, 2013). Accordingly, a knee flexion range of 25°–30° at the crank's bottom dead center is consistently recommended to improve biomechanical efficiency and reduce injury risk (Bini et al., 2011; Bini & Priego-Quesada, 2022). In contrast, flexion angles greater than 40° have been associated with discomfort, increased patellofemoral compressive forces, and an increased likelihood of pain development (Priego Quesada et al., 2017). Nevertheless, many amateur cyclists continue to ride with suboptimal configurations. Despite clear biomechanical guidelines, evidence on the direct impact of saddle adjustments on knee pain under real-world cycling conditions remains limited.

While the association between saddle height and knee pain has been recognized, longitudinal studies quantifying changes in pain before and after saddle fitting are scarce. Furthermore, few investigations have explored the short-term (immediate) and medium-term (two-week) effects of saddle height adjustment on pain reduction. Addressing these gaps is particularly important for amateur cyclists—the largest participant group worldwide—who are frequently exposed to inadequate bike setups and high training volumes.

This study examined the relationship between knee flexion angle and knee pain in amateur cyclists and evaluated the impact of saddle height adjustment on pain perception. We hypothesized that: (1) cyclists with excessive knee flexion (>40°) would report higher pain levels than those with optimal flexion (<40°); (2) saddle fitting that reduced flexion to the recommended 25°–30° range would produce both immediate and progressive reductions in pain. By addressing these questions, this study contributes to strengthening the biomechanical basis for evidence-based bike fitting as a preventive and therapeutic strategy in cycling.

Materials and methods

Participants

A longitudinal, quantitative correlational study was performed with 38 male amateur road and mountain bike cyclists aged 25–57 years (mean age: 40.3 ± 8.9), recruited from the Valparaíso Region, Chile. Participants were divided into two groups based on knee flexion angle: >40° (n = 21) and <40° (n = 17). Participant characteristics are summarized in Table 1. The average weight was 67.8 ± 7.9 kg, height 173.5 ± 6.0 cm, and a body mass index (BMI) 22.4 ± 1.9. Functional Threshold Power (FTP) averaged 224.7 ± 38.8 W, with a relative FTP of 3.3 ± 0.8 W/kg, and participants reported training an average of 225 ± 119.9 km per week (Table 1). All participants were fully informed about the study objectives, and written informed consent was obtained. The study was approved by the Institutional Ethics Committee of Universidad Viña del Mar (Reference Number: CEC-UVM 75-24).

Protocol

Participants used their own bicycles, each equipped with a Garmin power meter (Garmin Ltd, USA), which was calibrated according to the manufacturer's instructions before testing. Bicycles were mounted on a roller trainer (Feedback Sports Omnium Over-Drive, USA) for the study procedures. All cyclists were familiar with their FTP, which had been previously assessed either by themselves or by their coaches.

For the assessment, 20 mm reflective markers were placed on anatomical landmarks in accordance with the protocol described by Scoz et al. (2021). Markers were positioned on the fifth metatarsal head, lateral malleolus, greater trochanter, acromion, lateral epicondyle, and styloid process of the ulna. These placements allowed calculation of joint angles in the 2D sagittal plane, including the ankle, knee, hip, trunk, shoulder, and elbow (Figure 1A).

Marker placement was performed by a kinesiologist/physiotherapist with six years of experience in biomechanics and postural adjustment (bike fitting). A Sony HDR-CX405 camera, positioned 3.5 m from the roller, recorded the motion at a sampling rate of 50 Hz. Video analysis was performed using Kinovea software, version 2023.1.24 (General Public License).

After marker placement, participants completed two phases: a warm-up and a test. During the warm-up, cyclists pedaled for five minutes at 70 W and a cadence of 90 rpm. In the test phase, participants cycled for two minutes at their individual FTP while maintaining a cadence of 90 rpm. The final 30 s of pedaling were recorded, and the average joint angles over 15 consecutive cycles were calculated. Immediately following the test, participants reported any knee pain using a Visual Analog Scale (VAS; 0–10) (Figure 1B).

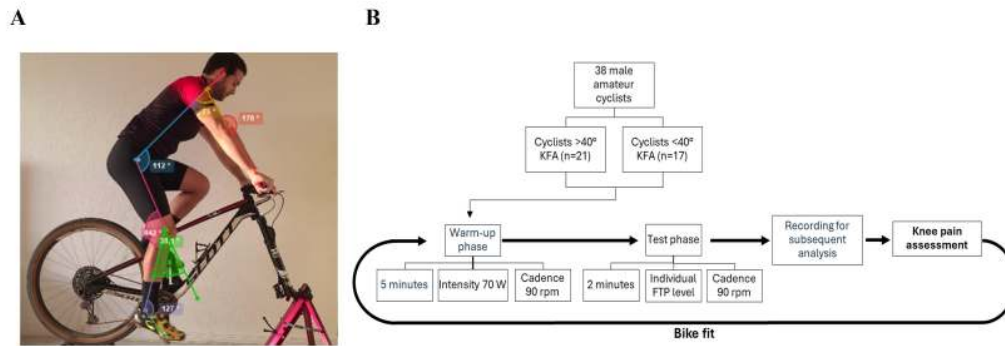


Figure 1. Knee angle measurement and experimental design. A. Body markers for 2D sagittal plane tracking and representation of the knee flexion angle (green). B. Schematic diagram of the experimental protocol

After the initial assessment, participants were instructed not to modify any bicycle component or measurement until the two-week follow-up. They were asked to maintain their usual weekly mileage to ensure a consistent evaluation of the long-term effects of the bike fit. After two weeks, participants were contacted by telephone to reassess knee pain during cycling. Using the same VAS, they reported any pain experienced during their two most recent rides.

Statistical analysis

The Shapiro–Wilk test was used to assess the normality of the data, and Bartlett's test evaluated the homogeneity of variances. For variables that violated assumptions of normality or homogeneity, log transformations were applied, with results subsequently back-transformed for presentation. Continuous data are expressed as means $\pm$ standard deviations. Differences between groups were analyzed using unpaired t-tests. Changes in knee pain before and after the bike fit were assessed using analysis of variance (ANOVA), followed by Tukey's post-hoc tests. Relationships between numerical variables were evaluated using Spearman's correlation to examine the association between knee flexion angle and knee pain. Correlation coefficients were interpreted as follows: 0.00–0.10 (very weak or no correlation), 0.10–0.39 (weak), 0.40–0.69 (moderate), 0.70–0.89 (high), and 0.90–1.00 (very strong). Knee flexion was treated as the independent variable, and knee pain as the dependent variable. Statistical analyses were performed using GraphPad Prism 8.0.1, and a general linear model was applied with significance set at $p < 0.05$.

Results

Table 1 presents the descriptive statistics of amateur male cyclists from Viña del Mar, categorized into two groups based on knee flexion: $>40^\circ$ and $<40^\circ$. Variables including age, weight, height, BMI, FTP, relative FTP, and weekly training distance were similarly distributed between the groups. As expected, both knee flexion angles and pain levels were significantly higher in the $>40^\circ$ group compared to the $<40^\circ$ group (t-test, $p < 0.05$). Following the bike fit—which involved adjustments to the saddle, cleats, and handlebars—no significant differences in knee flexion angles were observed ($p = 0.05$).

Table 1. Demographics, anthropometrics, body composition, functional threshold power, relative functional threshold power, weekly cycling distance, knee flexion angle, and pain

Parameters	Knee flexion angle $>40^\circ$ (n = 21)	Knee flexion angle $<40^\circ$ (n = 17)	p
Age (years)	41.6 $\pm$ 10.3	38.7 $\pm$ 7.1	0.3
Weight (kg)	68.9 $\pm$ 7.2	66.4 $\pm$ 8.7	0.75
Height (m)	1.736 $\pm$ 0.05	1.729 $\pm$ 0.07	0.35
Body mass index (kg/m ²)	22.8 $\pm$ 2.1	22.1 $\pm$ 1.47	0.25
FTP (W)	223.3 $\pm$ 33.9	226.5 $\pm$ 45.1	0.8
FTP relative (W/kg)	3.3 $\pm$ 0.7	3.5 $\pm$ 0.9	0.49
Km/week	261.4 $\pm$ 106.8	274.1 $\pm$ 137.6	0.75
Knee Flexion Angle PRE ($^\circ$)	43.8 $\pm$ 2.7	25.8 $\pm$ 5.7	0.0001
Knee Flexion Angle POST ($^\circ$)	27.5 $\pm$ 1.4	24.6 $\pm$ 1.2	0.052
Pain (PRE)	4.4 $\pm$ 1.9	0.9 $\pm$ 1.5	0.0001
Pain (POST)	2.7 $\pm$ 1.4	0.6 $\pm$ 1.0	0.0001
Pain (POST-2)	1.4 $\pm$ 1.6	0.2 $\pm$ 0.4	0.0069

FTP: Functional threshold power. Significant differences were evaluated using a t-test.

Effect of bike fit on pain

was evaluated at three time points for all participants: before the bike fit (PRE), immediately after the bike fit (POST), and two weeks after adjustment (POST-2). Figure 2A shows pain levels in participants with knee flexion $>40^\circ$. A two-way ANOVA indicated that pain immediately after the bike fit was significantly lower than pre-adjustment levels (PRE: 4.4 ± 1.9 ; POST: 2.7 ± 1.4). Pain further decreased at the two-week follow-up, with POST-2 values significantly lower than both PRE and POST (POST-2: 1.4 ± 1.6). Figure 2B shows pain levels in participants with knee flexion $<40^\circ$, where a two-way ANOVA revealed no significant differences across the three conditions ($p > 0.05$).

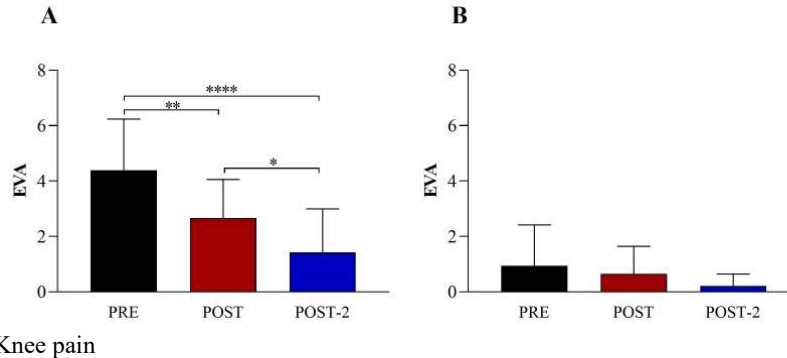


Figure 2. Effect of saddle adjustment on knee pain. A. Changes in knee pain among cyclists with a knee flexion angle greater than 40° . Pain before adjustment was significantly higher than both immediately after adjustment ($p < 0.01$) and two weeks later ($p < 0.0001$). B. Changes in knee pain among cyclists with a knee flexion angle less than 40° . No significant differences in knee pain were observed under any condition. * $p < 0.05$, ** $p < 0.01$, **** $p < 0.0001$

Association between the degree of knee flexion and pain

Figure 3 shows the relationship between knee flexion angle and pain levels. Across all participants, a significant positive correlation was observed ($r = 0.72$; Fig. 3A). Among participants with knee flexion $>40^\circ$, a moderate positive correlation was also found ($r = 0.51$; Fig. 3B). In contrast, no significant correlation was detected in participants with knee flexion $<40^\circ$ ($r = 0.12$; Fig. 3C). Following saddle height adjustment, all participants achieved a knee flexion angle between 25° and 30° . In this optimized posture, no significant correlation was observed between knee flexion angle and pain immediately after the bike fit (Fig. 4A) or at the two-week follow-up (Fig. 4B).

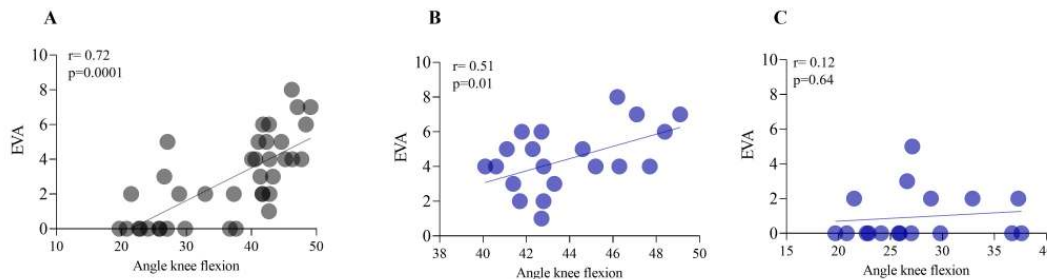


Figure 3. Correlation between knee flexion angle and knee pain. A. Across all participants, a strong correlation was found between knee flexion angle and knee pain ($r = 0.72$, $p = 0.0001$). B. Among cyclists with a knee flexion angle greater than 40° , a moderate correlation was observed ($r = 0.51$, $p = 0.01$). C. Among cyclists with a knee flexion angle less than 40° , a weak, non-significant correlation was found ($r = 0.12$, $p = 0.64$).

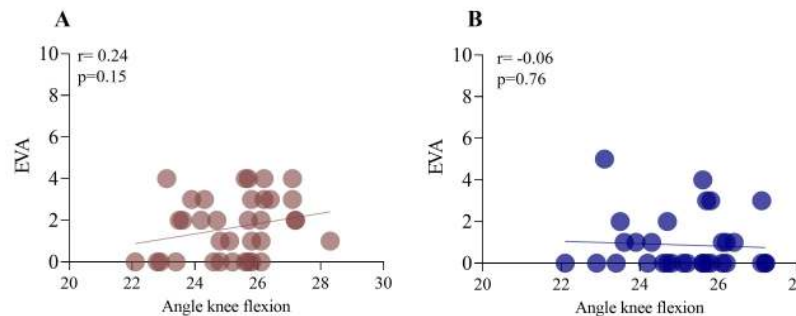


Figure 4. Correlation between knee flexion angle and knee pain after adjustment. A. Immediately after adjustment, a weak correlation was observed between knee flexion angle and knee pain ($r = 0.24$). B. Two weeks after adjustment, no correlation was found ($r = 0.06$).

Discussion

The aim of this study was to examine the relationship between knee flexion angles and the effects of saddle adjustment on knee pain. We found a strong positive correlation between knee flexion and pain, indicating that higher flexion angles were associated with greater discomfort. After saddle height adjustment, pain levels decreased significantly, with further reductions observed at the two-week follow-up compared to the pre-adjustment condition. The study focused only on male participants owing to the limited number of women who met the inclusion criteria and expressed interest in participating.

In participants with knee flexion $>40^\circ$, pain decreased significantly following the saddle adjustment and continued to decline at the two-week follow-up when the bicycle configuration reduced the angle to approximately 25° – 30° . These results highlight appropriate saddle height as an effective strategy for both injury prevention and performance optimization (Swart & Holliday, 2019). Similarly, Silberman (2013) recommended achieving a knee flexion angle of 25° – 30° at bottom dead center to minimize injury risk. Our findings align with this evidence, demonstrating that adjusting knee flexion to this range reduces pain and likely contributes to the prevention of overuse injuries. Furthermore, Holliday (2021) emphasized that bicycle configuration also influenced performance outcomes, reporting that factors such as saddle setback, handlebar position, and rider flexibility were significantly associated with power output and $\text{VO}_{2\text{max}}$. Collectively, this evidence suggests that proper adjustment of knee flexion angle may not only reduce the risk of injury but also improve cycling performance.

Our results are consistent with those reported by Priego-Quesada et al. (2017), who studied 20 male club-level cyclists. They reported that knee pain was significantly greater at a flexion angle of 40° compared to 30° and 20° ($p = 0.01$). Additionally, assessments of comfort indicated that a knee flexion of 30° was significantly more comfortable than 40° ($p < 0.01$), while a flexion of 20° was described as "neither uncomfortable nor comfortable" ($p < 0.05$). Notably, the participants in the study by Priego-Quesada et al. (2017) and those in our study had similar weekly training volumes.

We also observed that pain decreased both immediately and two weeks after the saddle adjustment. A previous study by Scoz et al. (2021) reported a significant reduction in pain 30 days after a saddle adjustment while using a roller. However, Scoz's study included both male and female amateur mountain bikers with varying training volumes, categorized into four groups, and assessed pain only after 30 days. In contrast, our study focused only on male cyclists with comparable training volumes, averaging approximately 260 km/week, and measured pain both immediately after the adjustment and at the two-week follow-up. These results suggest that pain reduction following a bike fit may be time-dependent.

The elevated pain levels reported by participants before the saddle adjustment may reflect the presence of, or increased risk for, future knee injuries. Bini et al. (2011) demonstrated that a knee flexion angle close to 25° reduces risk factors for overuse injuries, while greater angles increase the likelihood of such injuries. Other authors (Bressel, 2001) reported that knee flexion exceeding 40° generated a larger resultant force vector and changed the orientation of the quadriceps and patellar tendons, producing high compressive forces at the patellofemoral joint.

Furthermore, the assumption that excessive knee flexion ($>40^\circ$) affects only the sagittal plane warrants reconsideration. Wang et al. (2020) reported that a low saddle height was associated with an average 10% increase in knee adduction, or valgus movement, which may contribute to pain owing to suboptimal frontal-plane biomechanics during pedaling. In contrast, Hummer et al. (2021) found no association between increased knee flexion and valgus or adduction movements. These conflicting results highlight the need for future studies to investigate the relationship between knee valgus–varus alignment, knee flexion angle, and knee pain during cycling.

Conclusions

This study demonstrates a strong relationship between knee flexion angle and knee pain in amateur male cyclists. Excessive knee flexion ($>40^\circ$) was associated with higher pain levels, whereas adjusting the saddle to achieve 25° – 30° flexion at bottom dead center resulted in immediate and sustained pain reduction. These findings underscore the importance of proper bike fitting as both a preventive and therapeutic strategy.

From a practical perspective, maintaining optimal knee flexion can increase comfort, improve pedaling efficiency, and reduce the risk of overuse-related knee injuries. Coaches, clinicians, and cycling programs should incorporate routine bike fitting assessments to help minimize injury risk and optimize performance.

Theoretically, this study advances the biomechanical understanding of knee joint loading during cycling, demonstrating that simple adjustments can reduce patellofemoral stress and associated pain. Future research should include female cyclists, incorporate long-term follow-ups, and use 3D kinematic analyses to evaluate frontal-plane knee movements and overall biomechanics.

In summary, adjusting saddle height to achieve the recommended knee flexion range represents an effective, evidence-based intervention for reducing knee pain, providing practical guidance for cyclists and a foundation for further biomechanical investigations. During the preparation of this work, the author(s) used ChatGPT (OpenAI) to improve the grammar and clarity of the English language. After using this tool, the author(s) reviewed and edited the content as necessary and take full responsibility for the final publication.

Conflicts of interest: The authors declare no conflicts of interest.

Limitations

This study has both strengths and limitations. First, the sample included only male amateur cyclists. Previous research indicates that women may have different pain sensitivities and thresholds compared to men (Bartley & Fillingim, 2013). Therefore, sex should be considered in future studies on pain. Second, pain was evaluated only two weeks after the bike fitting, which may not provide enough time for full adaptation to the new position or for pain symptoms to fully manifest. However, this period was sufficient to observe a significant reduction in knee pain. Third, future studies should include a frontal assessment of knee movement (valgus and varus) to determine whether these motions are associated with pain. Ideally, this should be performed using 3D motion analysis to ensure greater accuracy and validity in both the frontal and sagittal planes (Fonda et al., 2014).

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