Influence of Saddle Height on Lower Limb Kinematics in Well-Trained Cyclists: Static Vs. Dynamic Evaluation in Bike Fitting

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Abstract

Ferrer-Roca, V, Roig, A, Galilea, P, and García-López, J. Influence of saddle height on lower limb kinematics in well-trained cyclists: Static vs. dynamic evaluation in bike fitting. *J Strength Cond Res* 26(11): 3025–3029, 2012—In cycling, proper saddle height is important because it contributes to the mechanical work of the lower limb joints, thus altering pedaling efficiency. The appropriate method to select optimal saddle height is still unknown. This study was conducted to compare a static (anthropometric measurements) vs. a dynamic method (2D analysis) to adjust saddle height. Therefore, an examination of the relationship between saddle height, anthropometrics, pedaling angles, and hamstring flexibility was carried out. Saddle height outside of the recommended range (106–109% of inseam length) was observed in 56.5% of the subjects. Inappropriate knee flexion angles using the dynamic method were observed in 26% of subjects. The results of this study support the concept that adjusting saddle height to 106–109% of inseam length may not ensure an optimal knee flexion (30–40°). To solve these discrepancies, we applied a multiple linear regression to study the relationship between anthropometrics, pedaling angles, and saddle height. The results support the contention that saddle height, inseam length, and knee angle are highly related ($R^2 = 0.963$, $p < 0.001$). We propose a novel equation that relates these factors to recommend an optimal saddle height (108.6–110.4% of inseam length).

Key Words cycling biomechanics, bike fit, anthropometrics, analysis of movement

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Introduction

In cycling, saddle height modifies the mechanical work of the lower limb joints (3) and alters the pedaling efficiency (10,11,13–15). Until now, several authors have proposed different bicycle fit methods to select an optimal saddle height as static evaluations (measurements at rest) or dynamic evaluations (measurements while riding) (18). Static evaluations (i.e., anthropometrics or goniometric) have been used more than dynamic (i.e., 2D motion analysis), possibly because of their simplicity, low cost, and easier use in bicycle shops (5).

For a static evaluation, anthropometric measures, such as trochanteric height and inseam length, have been widely used to adjust saddle height (2,5,11). For example, in terms of anaerobic power output, Hamley and Thomas (11) proposed the 109% of the inseam as the optimal saddle height. Nordeen-Snyder compared aerobic efficiency at 3 different saddle heights (101.7, 107.1, and 112.1%). According to other authors (5), 107% of inseam could be considered as optimum saddle height (11). Likewise, Gregor and Broker (9) suggested a range of 106–109% of inseam length as optimal seat height during cycling. These anthropometric studies considered the inseam as the distance from the ischium to the floor and measured the saddle height from the center of the pedal axle to the top of the saddle, when the crank is parallel to the seat tube. Goniometric evaluation was recommended by Holmes et al. (12) as a new static method to fit saddle height. In a static position, cyclists should achieve a knee angle of 25–35° with the pedal located at the bottom dead center (18) and not >115° with the pedal located in the top dead center (5). Recent studies demonstrated that riders reached their best aerobic performance when a saddle height that gave a knee angle of 25° was selected and emphasized that this method produced a different saddle height compared with that of Hamley and Thomas's method (14,15). However, it is also well known that using Holmes et al.'s method, the knee angle measurement depends on the ankle angle, and the knee flexion is higher while increasing ankle plantar flexion (3).

For a dynamical approach, 2D motion analyses were used in some studies where the effect of saddle height on knee angle was evaluated while pedaling (4,16,17). Although it was not recognized as a method to adjust saddle height in a recent review (3), a previous study recognized it as a dynamic method (18). Although its correspondence with Holmes et al.'s method is still unclear, it has been reported that lateral pelvic tilt (rocking from side to side) increases knee flexion by approximately 5–6° with respect to static goniometry evaluation (6). According to these findings, the knee flexion angle of 25–35° during a static evaluation could correspond with an angle of 30–40° during a dynamic evaluation (5,8,16). However, it has been shown than other variables such as hamstring flexibility could also affect knee angle during pedaling (dynamic evaluation), because hamstring length changes as saddle height changes, and this could condition the cyclists to select the saddle height according to his or her hamstring flexibility (12).

Given the variety of approaches, this study was conducted to compare static (anthropometric measurements) vs. dynamic methods (2D analysis) to adjust the saddle height. We examined the relationship between saddle height, anthropometrics, pedaling angles, and hamstring flexibility in well-trained riders, using their habitual bike fit. We hypothesized that Gregor and Broker's reference (106–109% of inseam length) would not ensure a knee flexion angle of 30–40° while pedaling. In addition, we hypothesized that hamstring flexibility could affect the saddle height selected by high-level cyclists.

Methods

Experimental Approach to the Problem

This study was performed partly as a result of conflicting findings in the literature regarding the different methods for recommending an optimal saddle height. Accepting that static methods have been used widely in the scientific literature (1), in this study, we hypothesized that a static method does not coincide with a dynamic one in high-level cyclists. A cross-sectional approach was used to solve this dilemma. The study sample was divided into 2 groups according to Gregor and Broker's reference (Table 1). The cyclists that selected a relative saddle height outside of 106–109% were clustered in group A ($n = 10$), whereas cyclists with a relative saddle height inside the range were clustered in group B ($n = 13$). One-way analysis of variance (ANOVA) was done to identify differences between groups A and group B. After that, a multivariable analysis was used to find the relationship between the dependent variable (saddle height) and the independent variables (inseam length, knee flexion angle, hip flexion angle, ankle flexion angle, hamstring flexibility, and saddle back).

Subjects

Twenty-three high-level male cyclists participated in this study (21.8 ± 3.5 years, 67.8 ± 6.8 kg, 1.77 ± 0.04 m). All of them were healthy male competitors (Continental and under 23 UCI categories) with several years' cycling experience. They were tested at the end of the preparation period (February), just before starting the competitions (9,222 ± 1,862 km of training). The evaluation protocol was designed according to the Helsinki Conference for research on human beings, and all the cyclists signed informed consent before starting the study. The study Protocol was approved by the Committee of Ethics in Research of the Institution where this study was conducted.

Procedures

All the cyclists were evaluated at the same time of the day (in the morning, between 09:00 and 12:00), under similar environmental conditions (21–23° C, 60–65% relative humidity), After a 24-hour period with no hard training, the subjects reported to our laboratory (~100-m altitude). They were able to drink water ad libitum to avoid dehydration. Initially, an anthropometric tape (Holtain Ltd.; Crymych, United Kingdom) was used to measure saddle height, saddle back, stem height, and inseam length by the same researcher. For the results to be comparable with that of the Gregor and Broker method (9), saddle height was measured from the center of the pedal axle to the saddle top, with the pedal at the most distal end. In addition, saddle height was divided by inseam length to get the riders' relative saddle height.

To perform the 2D analysis, reflective markers of a 15-mm diameter were attached to the greater trochanter, the lateral femoral condyle, the lateral malleolus, and the lateral aspect of the fifth metatarsal-phalangeal joint. After a 10-minute warm-up, the cyclists performed a 6-minute trial at 90–100 rpm on a free training roller (Tacx Antares Roller T1000.Tacx; Wassenaar, Netherlands). They used their own bike, cycling shoes, and clipless pedals while pedaling with the hands in a dropped position. Sagittal videos at 50-Hz sampling frequency were acquired during the last 2 minutes of the trial from each cyclist's right lower limb by a single camera perpendicular to the movement plane and 10 m away from the subject. The recorded videos were analyzed on a computer using a commercial software program (TCD2008. SportSuport Online S.L; Barcelona, Spain). A single experimenter estimated the sagittal hip, knee, and ankle angles following Nordeen-Snyder's convention (13) directly on the video image by marking the reflective markers attached. We calculated the mean of the sagittal plane angles of 5 pedaling cycles of every trial. According to Umberger and Martin (19), sagittal plane kinematics of the hip, knee, and ankle during cycling were similar to the respective angles measured in 3D.

After the cycling test, the cyclists' hamstring flexibility was measured by the passive knee test. Following Fredriksen et al. (7), measurement of the knee extension angle was made with the subject lying supine and the leg being measured held at 90°. The subjects were also instructed to keep their low back flat on the table to limit further possible pelvic rotation during the measurement. Hip flexion position was

TABLE 1. Mean, *SD*, and range of the characteristics of the subjects and their bicycles.*†

	Group A ($n = 10$)		Group B ($n = 13$)	
	Mean ± *SD*	Range	Mean ± *SD*	Range
Age (y)	21.1 ± 3.5	18.3–29.0	22.4 ± 3.5	18.6–29.3
Mass (kg)	69.3 ± 8.8	57.4–89.0	66.6 ± 4.8	54.6–72.9
Height (cm)	178.5 ± 1.6	171.2–188.6	176.3 ± 3.8	170.7–183.0
E (cm)	87.0 ± 5.2	82.6–91.7	82.5 ± 3.4‡	78.4–87.7
SH (cm)	93.9 ± 3.1	88.4–99.8	91.4 ± 3.3	87.2–96.3
SHE (%)	107.8 ± 0.8	106.0–108.9	110.7 ± 1.0‡	109.3–112.3
SB (cm)	7.6 ± 1.9	4.0–10.9	5.8 ± 1.1‡	4.3–7.8

**E* = inseam length; SH = saddle height; SHE = saddle height relative to the inseam length; SB = saddle back.
†Group A (cyclists with a seat height between 106 and 109% of inseam length) and group B (cyclists with a seat height >109% of inseam length).
‡Significant differences ($p \leq 0.05$) between group A and group B.

maintained while the lower leg was passively moved into the final position of knee extension. The final position was defined as the point at which the experimenter perceived resistance to stretch. A sagittal plane video was recorded during the test. After that, a 2D analysis was carried out to measure the knee angle in the final position (TCD 2008 software; SportSuport Online S.L; Barcelona, Spain). Previous studies reported that this test had appropriate intratester and intertester reliability in measuring hamstring flexibility (7).

Statistical Analyses

Descriptive data are expressed as arithmetic mean ± *SD*. Statistical analysis was carried out using SPSS+ version 15.0 (Chicago, IL, USA). The Kolmogorov-Smirnov test was applied to ensure a Gaussian distribution of the results. One-way ANOVA was performed to identify the differences between group A and group B. Newman-Keuls post hoc analysis was used to establish statistical differences between means. After that, a multivariable analysis was used to find the relationship between the dependent variable (saddle height) and the independent variables (inseam length, knee flexion angle, hip flexion angle, ankle flexion angle, hamstring flexibility, and saddle back). Intraclass correlation coefficient (ICC) was determined to assess intratester reliability. To do this, all the subjects were measured twice by the same observer. The time between measurements was approximately 3 months. The ICC values were 0.91 for the hip angle, 0.96 for the knee angle, 0.92 for the ankle angle, and 0.97 for the knee angle in the passive knee test. Statistical significance was set at $p \leq 0.05$, whereas a trend was noted when $p \leq 0.10$.

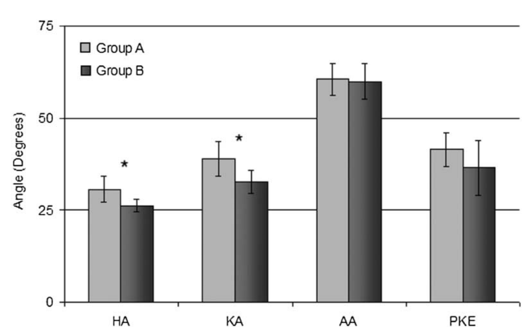

Figure 1. Comparison between group A (cyclists with a seat height between 106 and 109% of inseam length) and group B (cyclists with a seat height >109% of inseam length) for the lower limb flexion angles performed during the 6-minute trial and the passive knee extension test. Hip angle (HA), Knee angle (KA), Ankle angle (AA) and Passive knee extension angle (PKE). Data is expressed in degrees. *Values are significantly different, $P \leq 0.05$.

RESULTS

All the subjects completed the testing sessions without any incidents or injuries. The relative saddle height selected by 43.5% of the riders was inside the range of 106–109% of inseam length (group A). The rest of the cyclists (56.5%) chose a higher relative saddle height (group B). Therefore, none of the riders used a saddle height <106%, and the entire group B selected a saddle height >109%.

During the dynamic evaluation, 50% of group A worked out with a knee flexion angle outside the recommended range (30–40°). On the other hand, in group B, 7.7% presented knee angles outside of this range. Differences between group A and group B are given in Table 1 and Figure 1. The ANOVA showed significant differences between both groups in inseam length ($F = 11.595$, $p < 0.05$), hip angle ($F = 15.995$, $p < 0.001$), knee angle ($F = 14.746$, $p < 0.001$), relative saddle height ($F = 45.693$, $p < 0.001$), and saddle back ($F = 8.122$, $p < 0.05$). The riders in group B had lower inseam length, and they selected a higher saddle height relative to the inseam and shorter saddle setback. In addition, they worked out with lower values of hip angle and knee angle than group A did. Although no differences were found in the passive knee test, they were close to statistical significance ($p = 0.08$).

In the multiple regression analysis, independent variables inseam length and knee angle were taken into account to predict saddle height ($R^2 = 0.937$, $p < 0.001$):

$$SH = 22.1 + (0.896\,E) - (0.15\,KA),$$

where SH, the saddle height, is in centimeters, E is the inseam length in centimeters, and KA is the recommended knee angle in degrees (30–40°).

Discussion

The main finding of this study was that static (anthropometric measurements) and dynamic (2D analysis) methods to adjust the saddle height in high-level cyclists did not coincide. The cyclists in group A selected a relative saddle height of 107.8% (±0.8%). Hence, according to static method theories, we could assert that these riders had chosen optimal conditions (9). Nevertheless, when we analyzed the knee angle during cycling (dynamic method), we found that 50% of this group worked out with excessive flexion, exceeding the limit of 40°, with the crank parallel to the seat tube and the pedal located close to the bottom position. In group B, we found different results, and only 7.7% of the riders exceeded this limit. To solve these discrepancies, a multiple linear regression was applied. Saddle height was predicted ($R^2 = 0.937$, $p < 0.001$) taking into account inseam length (static method) and knee angle (dynamic evaluation). If these variables were replaced in the equation by the recommended reference of 30–40° and the mean inseam length of our riders (93.9 ± 3.1 cm), we would obtain a saddle height range of 108.6–110.4% of inseam. In a similar line to our results, Peveler demonstrated in 3 different studies that using 109% of inseam was outside the recommended limits to improve cycling economy (25–35° static knee angle) (15). Furthermore, our range of relative saddle height is higher than the limits recommended by other authors, where riders used toe-clip pedals (11,13). In our case, as in modern cycling, the cyclists worked out with clipless interfaces. This probably caused an increment of knee flexion angle and required a higher position of the saddle compared with the toe-clip pedal configuration. At this point, we would like to point out that it is possible that the majority of the equations for predicting seat height from inseam length (2,11,13) were obtained with toe clip instead of clipless pedals (around the 1990s). Further studies are required to confirm this hypothesis, by comparing knee angles while pedaling with these 2 types of pedals.

When examining the kinematic results of the 2 groups, we can see that a lower selected saddle height relative to the inseam caused an increment of the knee angle and hip flexion angle while cycling with the crank parallel to the seat tube and the pedal located close to the bottom position. These findings confirm the suggestion of other authors (4,10,13) that hip and knee joints are sensitive to saddle height changes. Contrary to other studies, saddle height changes did not show any influence on ankle kinematics (3,13). Nordeen-Snyder (13) reported that plantar flexion at bottom dead center increased by 8% with increases in saddle height. In this study, these differences were probably caused by the large change in saddle height, from 107.1–112% of inseam. We did not find this relationship, possibly because of the lack of riders who selected a saddle height of 112% of inseam.

Another purpose of this study was to determine if hamstring flexibility could affect the saddle height selected by well-trained cyclists. We carried out the passive knee test to evaluate the hamstring flexibility of the riders. Bandy and Irion (1) defined a subject with limited hamstring muscle as having a passive knee flexion angle >30° measured with the femur held at 90° of hip flexion. With this consideration in mind, both groups had limited hamstring muscles, because group A reached 41.3 ± 4° and group B reached 36.5 ± 7.4°. Considering that inflexibility of the hamstring-muscle groups was related to a greater flexion of the knee (20) and that riders with tight hamstring muscles tend to select a lower saddle position ($p = 0.08$), we think that further studies should be conducted with a greater sample to determine if low-level hamstring flexibility could have an influence on the position of the cyclist and the bicycle setup.

In conclusion, this study indicates that a static method based on anthropometric measurements (106–109%) does not ensure an optimal knee angle during pedaling (30–40°) in high-level cyclists. This could be because the majority of the studies for predicting seat height from inseam length, which were done a long time ago (around the 1990s), when toe clip instead of clipless pedals were used. Another possibility is the influence of hamstring flexibility related to this relation, although further studies with a greater sample should be conducted to confirm this hypothesis. This study proposes a new range of inseam length to estimate seat height when clipless pedals are used (108.6–110.4%). Future studies should compare knee angles while pedaling with these 2 types of pedals. Additionally, further experimental and longitudinal studies are required to evaluate the effects of previous training adaptation on the optimal reference (static vs. dynamic) for setting the bicycle saddle height.

Practical Applications

Saddle height is an important factor of a correct bike set up for an optimized performance. Until now, several authors have proposed different bicycle fit methods to select an optimal saddle height. This study was conducted to compare a static (anthropometric measurements) vs. a dynamic method (2D analysis) to adjust the saddle height. Ours results support the view that adjusting saddle height from 106 to 109% of the inseam (static method) does not ensure an optimal knee angle while pedaling (dynamic method), because these references could be valid only to toe-clip pedals instead of clipless pedals. We propose a novel equation (SH = 22.1 + [0.896E] − [0.15KA]) that relates the inseam length (E) and the recommended knee angle while pedaling (KA) to set an optimal saddle height (SH) using the modern pedals. As a result of this equation, a new saddle height range of 108.6–110.4% of inseam is suggested. Changes in saddle height modify the range of motion and the mechanical work of the lower limb joints. Consequently, we suggest making these changes in small increments, especially in cyclists with limited hamstring flexibility. Besides anthropometrics, we recommend that coaches should consider a kinematic analysis of their bicycle configuration to optimize pedaling efficiency.

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