STATIC VERSUS DYNAMIC EVALUATION IN BIKE FITTING: INFLUENCE OF SADDLE HEIGHT ON LOWER LIMB KINEMATICS

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The purpose of this study was to verify if high-level cyclists achieve an appropriate kinematic pattern using their habitual bike fit. Twenty-three elite cyclists participated in the study. Many riders, 56.5%, used a habitual bike fit in which the saddle height was outside of the recommended range from 106% to 109% of the inseam. Surprisingly, however, we found an inappropriate knee flexion angle in only 26% of all the cyclists. Nevertheless, our results support the view that adjusting saddle height from 106% to 109% of the inseam would not prevent knee injuries in well-trained cyclists. Results support the contention that saddle height, inseam length and knee angle are highly related (R^2=0.963 and p<0.001). We propose a novel equation that relates these factors in order to recommend an optimal saddle height.

KEY WORDS: Road cycling, biomechanics, anthropometrics, cycling position, overuse injuries.

INTRODUCTION: In cycling, saddle height modifies the mechanical work of the lower limb joints (Bini, Tamborindeguy, & Mota, 2010) and alters the pedaling efficiency (Nordeen-Snyder, 1977). In fact, it is generally considered that an incorrect saddle height (too low or too high) predisposes cyclists to overuse injuries (Silberman, Webner, Collina, & Shiple, 2005) such as patellofemoral pain (de Vey Mestdagh, 1998; Wheeler, Gregor, & Broker, 1995) or iliotibial band syndrome (Holmes, Pruitt, & Whalen, 1993)

To date, 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) (Silberman, et al., 2005). Static evaluations (i.e. anthropometrics or goniometric) have been more used than dynamic ones (i.e. two-dimensional motion analysis), possibly due to their simplicity, low cost and easier use in bicycle shops (de Vey Mestdagh, 1998)

For a static evaluation, anthropometric measures as trochanteric height and inseam length have been widely used to adjust saddle height (Belluye & Cid, 2001; de Vey Mestdagh, 1998; Hamley & Thomas, 1967). For example, in terms of anaerobic power output, Hamley and Thomas (Hamley & Thomas, 1967) proposed the 109% of the inseam as the optimal saddle height. Nordeen-Snyder compared aerobic efficiency at three different saddle heights (101.7, 107.1 and 112.1%). According with other authors (de Vey Mestdagh, 1998), 107% of inseam could be considered as optimum saddle height (Hamley & Thomas, 1967). In the same line, Gregor and Broker (1991) suggested a range of 106-109% of inseam where VO_2 was minimized. These anthropometric studies considered the inseam as the distance from the ischium to the floor and measured the saddle height from the centre 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, Pruitt and Whalen (Holmes, et al., 1993) as a new static method to fit saddle height. In a static position, cyclists should achieve a knee angle of 25-30º with the pedal located at the bottom dead centre (Silberman, et al., 2005) and not more than 115º with the pedal located in the top dead centre (de Vey Mestdagh, 1998). Recent studies demonstrated that riders reached their best aerobic performance when selected a saddle height which gave a knee angle of 25º, and emphasized that this method produced a different saddle height compared to Hamley and Thomas's method (Peveler & Green, 2010)

For a dynamical approach, two dimensional motion analysis was used in some studies where the effect of saddle height on knee angle was evaluated while pedaling (Bini, et al., 2010; Price & Donne, 1997; Sanderson & Amoroso, 2009). It has been reported that lateral pelvic tilt (rocking from side to side) increases knee flexion by approximately 5–6º with respect to static goniometry evaluation (Farrell, Reisinger, & Tillman, 2003). According with these studies, to avoid injuries, other authors suggested an optimum knee angle of 30-35º while riding with the crank parallel to the vertical tube of the bicycle and pedal located close to the bottom position (García-López et al., 2009).
Given the variety of approaches, the present study was conducted to compare static versus dynamic evaluations in order to adjust an optimal saddle height. We examined the relationship between saddle height, anthropometrics and pedaling angles in well-trained riders, using their habitual bike fit. We hypothesized that a saddle height of 106%-109% of the inseam would not ensure an optimal knee flexion angle to prevent injuries (30-40º with the crank parallel to the vertical tube)

METHODS: Twenty three male cyclists (Continental and under 23 category) participated in this study. Means and standard deviations (SD) for age, body mass, and height were 21.8 ± 3.5 years, 67.8 ± 6.8 kg, 1.77 ± 0.04 m. All participants signed an Informed Consent Term in agreement with the Committee of Ethics in Research of the Institution where this study was conducted. Initially, an anthropometric tape was used to measure saddle height (Gregor and Broker, 1991), Saddle setback, Stem height and inseam length (Belluye and Cid, 2001) by the same researcher. In addition, saddle height was divided by inseam to get the riders' relative saddle height.
The study sample was divided into two groups. The cyclists that selected a saddle height outside of 106% to 109% of inseam were clustered in Group A, while cyclists with a saddle height inside the range were clustered in Group B. Using double-sided adhesive tape, reflective markers of 15 mm in diameter were attached to the greater trochanter, the lateral femoral condyle of the femur, the lateral malleolus and the lateral aspect of the fifth metatarsal-phalangeal joint. After a 5 minute warm up, cyclists performed a 2 minute trial at 90-100 rpm on a free training roller. They used their personal bike, cycling shoes and clipless pedals. Sagittal-kinematic variables were acquired from each cyclist's right lower limb by a single camera perpendicular to the movement plane and 10 m away from the subject. The images were acquired at 50Hz sampling frequency. A two-dimensional analysis (TCD 2008; SportSuport Online S.L.) was done and Nordeen-Snyder's convention (1977) was followed to measure the hip , knee and ankle flexion angle.
All statistical analysis of the data was carried out in SPSS version 15.0 (Chicago, IL, USA). Data are presented as means (±SD). One-way ANOVA was done to identify differences between groups A and B. The criterion for significance was set an alpha level of 0.05. A multivariable analysis was used to find the relationship between the dependent variable saddle height and the independent variables, inseam and knee angle.

RESULTS: The saddle height selected by 43.5% per cent of the riders was inside the range of 106% - 109% of the inseam (Group A). The rest of the cyclists (56.5%) chose higher saddle heights (Group B). Therefore, none of the riders used a saddle height lower than 106% and the entire group B selected a higher saddle height than 109% (Table 1).
During the test cycling session, 50% of Group A worked out with a knee flexion angle outside of the dynamic recommended range to prevent injuries (30º - 40º). On the other hand, in Group B, 7.7% presented a knee angle outside of this range. Differences between group A and group B are displayed in Table 1. ANOVA showed significant differences in inseam length between both groups ($F= 11.595$ and $p<0.05$), hip angle ($F= 15.995$ and $p<0.001$) , knee angle ($F= 14.746$ and $p<0.001$), saddle height ($F=45.693$ and $p<0.001$) and saddle setback ($F=8.122$ and $p<0.05$). The riders of the group B had lower inseam and they selected 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.

Table 1
Differences between group A and group B

Variables	Group A (n= 10)		Group B (n=13)	
	Mean ± SD	Range	Mean ± SD	Range
Age (Years)	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	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 ± 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 - 108.9	110.7 ± 1.0 *	109.3 - 112.3
HA (º)	30.7 ± 3.5	23.6 - 35.2	26.2 ± 1.7 *	24.0 - 29.6
KA (º)	38.9 ± 4.7	28.8 - 46.2	32.7 ± 3.1 *	27.0 - 39.8
AA (º)	60.5 ± 4.3	55.1 - 68.2	60 ± 4.8	51.5 - 67.2
SB (cm)	7.6 ± 1.9	4.0 - 10.9	5.8 ± 1.1*	4.3 - 7.8

Note: E =inseam length; SH = saddle height; SHE = saddle height relative to the inseam; HA = hip angle; KA = knee angle; AA = ankle angle; SB = saddle setback. *Significant difference between group A and group B ($p<0.05$).

On the multiple regression analysis computed with pooled sample, independent variables inseam length and knee angle were taken into account to predict (R^2=0.937, $p<0.001$)
Equation 1: $SH = 22.1 + (0.896 \cdot E) - (0.15 \cdot KA)$
where saddle height is SH in cm, inseam length is E in cm and knee angle is KA in degrees.

DISCUSSION: To improve performance and prevent injuries, it is essential for cyclists to have a properly adjusted saddle height. Cyclists in group A selected a saddle height of 107.8% (± 0.8). Hence, according to static method's theories, we could assert that these riders had chosen optimal conditions to achieve the best aerobic efficiency. Nevertheless, when we analysed the knee angle during cycling (dynamic method), we found that 50% of this group worked out with an excessive flexion, exceeding the limit of 40º with the pedal located at the bottom dead centre. Some authors suggested that overpassing this angle could increase anterior knee stress, mainly on patellar and quadriceps tendons (Bailey, Maillardet, & Messenger, 2003; Faria, 1992). In Group B, we found different results. Riders of this group had lower inseam and logically, they chose a lower saddle height. However, the position of the saddle relative to the inseam was higher than group A. This last could provoke that they worked out with lower hip and knee flexion angle. However, only a 7.7% of the riders fell outside of the injury prevention range (knee flexion of 30-40º). These results confirm a substantial discrepancy between static and dynamic methods to recommend an optimal saddle height.
When examining the kinematic results of the two groups, we can see that a lower selected saddle height relative to the inseam caused an increment of the knee and hip flexion angle while cycling with the crank parallel to the vertical tube and pedal located close to the bottom position. These findings confirm the suggestion of other authors (Bini, et al., 2010; Nordeen-Snyder, 1977) 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. Nordeen-Snyder (Nordeen-Snyder, 1977) reported that plantar flexion at bottom dead centre increased by 8% with increases in saddle height. Probably, in that study these differences were caused because of the large change in saddle height, from 107.1% to 112% of inseam . We did not find this relationship, possibly due to the lack of riders that selected a saddle height of 112% of inseam.

Saddle height was predicted (R^2=0.937; p<0.001) taking into account inseam length and knee angle. If these variables were replaced in the equation by the recommended 30-40º (Price and Donne, 1997) and the mean inseam length of our riders (93.9 ± 3.1 cm), we would obtain a saddle height range of 108.6% to 110.4% of inseam length. In a similar line to our results, Peveler (2008) highlighted that when saddle height was set using 109% of inseam, only 37% of the subjects worked out with knee angle inside the limits to prevent knee injuries (goniometric evaluation). As we can see, our range of saddle height relative to the inseam is higher than the limits recommended by other studies, where riders used toe-clip pedals. (Hamley & Thomas, 1967; Nordeen-Snyder, 1977). In our case, cyclists worked out with clipless interfaces that probably caused an increment of knee flexion angle and induced a higher position of the saddle compared with the toe-clip pedal configuration. Further studies are required to confirm this hypothesis.

CONCLUSION: The results of the present study support the view that adjusting saddle height from 106% to 109% of the inseam would not ensure an optimal knee flexion angle and might not prevent injuries (30-40º with the crank parallel to the vertical tube). Therefore, we suggest selecting a saddle height between 109-110.4% of inseam length could be more appropriate to prevent these types of injuries. Besides anthropometrics, we recommend that coaches and sports scientists should consider a kinematic study to individualize the bicycle set-up and prevent injuries.

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