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Importance of static adjustment of knee angle to determine saddle height in cycling

José Ignacio Priego Quesada[1]✉, Tiago C Jacques[2], Rodrigo R Bini[3] and Felipe P Carpes[4]

Abstract

Knee flexion angle is used to determine saddle height during pedaling. However, it is unclear if knee flexion angle at upright standing posture affects measures and interpretation of knee flexion angle during cycling. The objective of this study was to assess the importance of adjusting knee angle during pedaling according to the knee angle at upright posture. Seventeen cyclists performed three 10 min cycling trials at different saddle heights to induce knee flexion angles (40º, 30º or 20º when crank was at the 6 o'clock position). Knee flexion angle was determined at the sagittal plane during cycling using a 2D motion analysis system. Alteration of saddle height was performed by subtracting the knee flexion angle determined during an upright standing posture from the observed knee flexion angle during cycling. Repeatability of knee angles at upright posture in the three trials was very good (ICC=0.73). A reduction in knee flexion angle of 10.6° (95%CI [8.6, 12.6º]) during cycling was found using the adjustment for upright standing posture (p<0.01; effect size>3.0). As a result, saddle height is affected by adjustments based on knee angle measured in upright standing posture. Determining saddle height without adjusting knee angle for upright standing posture could lead to errors with possible effects on performance and/or injury risk.

Keywords: joint range of motion; kinematics; bike fitting; cycling posture.

✉**Contact email:** *j.priego.gibd@gmail.com* (JI Priego Quesada)

[1] *Biophysics and Medical physics group, Department of Physiology. Faculty of Medicine, University of Valencia, Valencia, Spain. Research Group in Sport Biomechanics (GIBD), Department of Physical Education and Sports, University of Valencia, Valencia, Spain.*

[2] *The Swedish School of Sport and Health Sciences, Stockholm, Sweden*

[3], *School of Physical Education of the Army, Brazilian Army Center for Physical Training, Rio de Janeiro, RJ, Brazil*

[4]. *Applied Neuromechanics Group, Laboratory of Neuromechanics, Federal University of Pampa, Uruguaiana, RS, Brazil*

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Introduction

Knee flexion measured when the crank arm is at the bottom of the pedalling stroke is the most used method in the determination of optimal saddle height in cycling (Bini et al. 2011; Fonda et al. 2014). It involves measurements of joint angles taken from static poses on the bike (Bini et al. 2014) and with motion capture during pedaling (Fonda et al. 2014) (Figure 1-A). Knee flexion angles between 25º and 30º seem to minimize injury risk and optimize cycling efficiency (Bini et al. 2011). Ferrer-Roca et al. (2012) suggested that this recommended range should be used in static methods (e.g. static pose), while a range between 30° and 40° should be more appropriate for dynamic methods (e.g. motion capture). However, it is unclear if this difference in recommended ranges of knee angle results from kinematic changes during cycling or from the method adopted to determine knee flexion angles.

Information taken from an upright standing posture was previously used to adjust joint angles offsets in three-dimensional motion analyses (Nielsen and Daugaard 2008; Jones et al. 2009) and in isometric knee extensions (Savelberg and Meijer 2003) (Figure 1-B). However, it has not been the case for two-dimensional assessment of knee motion in cyclists. While a previous study assessed static upright standing posture to adjust knee angles measured during pedalling (Peveler et al. 2012), others did not report this adjustment (Ferrer-Roca et al. 2012; Fonda et al. 2014). In fact, for most cyclists, a static upright standing posture elicits some degree of knee flexion (Figure 1-B), which may affect maximum knee extension during pedaling. These methodological differences between studies lead to limitations in comparing their results and to determine recommended knee flexion ranges during cycling. Here we hypothesized that the adjustment of knee angle during pedaling by knee angle measured at static upright standing posture may assist in more accurate kinematic data obtained from motion capture. The adjustment may also mitigate different anatomical proportions (i.e. legs and shanks) of cyclists and may help minimizing different markers' placement between cyclists and between assessment trials.

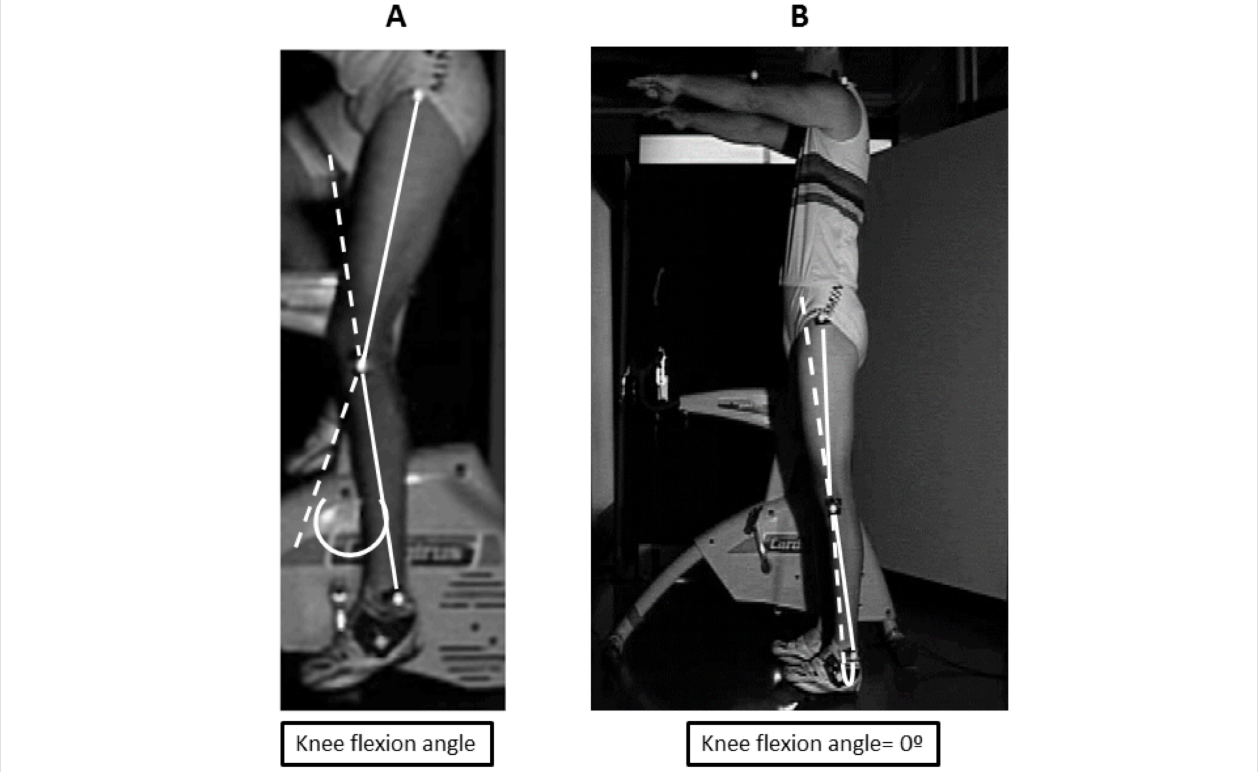

Figure 1. . A. Knee flexion angle during pedaling with the crank at 180° (6 o'clock). B. Static upright posture and flexion knee angle. Solid lines illustrate thigh and shank while dashed lines illustrate their projections.

A proper position on the bicycle was previously related to minimize injury risk (Callaghan 2005; Silberman et al. 2005). The knee is referred to be one of the most common sites of injuries in cyclists, especially for overuse injuries (Clarsen et al. 2010, 2015; Bini and Alencar 2014; Palmer-Green et al. 2014). An excessive knee flexion angle resulting from a low saddle height seems to be the main factor contributing for knee injuries (Holmes et al. 1994; Callaghan 2005; Deakon 2012), while excessive knee extension promoted by a higher saddle height has been found to increase risk of hamstrings muscle stress (Deakon 2012; Silberman 2013). Additionally, some studies observed that increases in maximum knee flexion from 25º to 35º could result in a reduction of cycling economy (VO_2, heart rate, and rating of perceived exertion) and anaerobic mean power output (Peveler & Green, 2011; Peveler, Pounders, & Bishop, 2007).

Given the previous assumptions, a proper determination of saddle height, which is closely related to the knee angle during pedaling, has an important role in injury risk and probably some effects on cycling performance. Differences in the determination of the knee flexion angles based on methods that use or not the static upright standing posture to adjust knee angle can lead to uncertainties in the determination of the saddle height. The objective of this study was to determine the differences in knee angle and saddle height between adjusted knee flexion angles during pedaling using knee angles from a static upright posture and a non-adjusted condition. We also analyzed the repeatability of the knee angle in the static upright posture in order to asses if this angle could elicit similar measurements between evaluation sessions. It was hypothesized that significant differences would occur between adjusted and non-adjusted measures of knee angle, which could have implications for bike fitting and comparison between research studies.

Materials and methods

Participants

Seventeen participants, categorized as club cyclists following the criteria defined by Ansley and Cangley (2009), volunteered for this study. At the time of the experiments, they were 31 ±11 years old, presented body mass of 75 ±10 kg, height of 178 ±7 cm, inseam length of 98.8 ±7 cm, and had and average cycling training volume of 198 ±130 km/week (mean ±SD). All cyclists signed a consent term in agreement with the Declaration of Helsinki, approved by the Ethics Committee in Research with Humans of the local institution and according to international standards (Harriss and Atkinson 2011).

Procedures

Participants completed three tests in different days (cross-over experimental design in random order) all of them using the same cycle ergometer. Cyclists were asked to avoid high-intensity exercise at least 24 h before each test. In the first session, an anthropometric tape, a stadiometer (Messband 206, Seca, Hamburg, Germany) and a weight scale (Edge YB02, Tecnovita by BH, Vitoria-Gasteiz, Spain) were used to measure inseam length, height and body mass, respectively. In each session they pedaled on a cycle ergometer

(Cardgirus Medical, Bikemarc, Sabadell, Spain) configured with different saddle heights in order to elicit specific knee flexion angles (40º, 30º or 20º with crank arm at 6 o'clock position in static poses - Figure 1.A). Cyclists exercised continuously for 10 min at moderate perceived exertion [value of 3 in the 10-grade scale of Borg (Borg 1982)]. Each cyclist performed the first test at freely chosen cadence between 70 and 90 rpm, and this chosen cadence was established for the other two tests. Pedaling cadence was controlled by visual feedback from cycle ergometer head unit. The saddle height used for each particular knee flexion angle was measured from the central portion of the top of the saddle of the cycle ergometer to the pedal spindle with the crank aligned with the seat tube (Bini et al. 2011).

Kinematic procedures and analysis were performed in all tests by the same evaluator to reduce between-evaluators variability in marker placement. Before the cycling test, reflective markers were placed at the lateral malleolus, lateral femoral condyle and greater trochanter of the left lower limb. Left limb was selected due to the laboratory configuration for cycle ergometer and camera position. Movements in the sagittal plane were captured at 50 frames per second with an image resolution of 1440 x 1080 pixels using a video camera (Sony Handycam HDR-FX1 Sony Corp., Tokyo, Japan) placed 3 m perpendicular to the motion plane and 1 m height from the floor. Left sagittal plane kinematics were captured and analyzed using a motion analysis software (Kinescan/IBV System, Valencia, Spain). Before measurements, optical distortion of the camera lens and calibration of the space were performed using a square object of known dimensions in which four space references were attached. Calibration was performed via 2D DLT using the motion analysis software. Spline smoothing method was used automatically in the motion analysis software (Woltring, 1986). A bidimensional kinematic model of three markers (lateral malleolus, lateral femoral condyle and greater trochanter) defining two segments (thigh and shank) was used. Knee flexion angle was calculated by the projected β angle between these two segments (Fonda et al. 2014). A correction factor consisting in adding 2.2° to the measurements was performed (Fonda et al. 2014) in order to amend potential mediolateral leg motion. Measurements of knee angle at the static upright position were performed before exercise (Figure 1-B). After that, adjusted knee flexion angle during cycling was calculated subtracting the static upright flexion knee angle from the dynamic flexion knee angle. Additionally, trunk flexion was maintained between 40° and 50° (angle between the horizontal axle and the trunk) and shoulder flexion between 75°–90° (angle between the upper arm and the trunk) for all the conditions tested. Horizontal posture of the saddle was defined by the plummet method (Zani 2010).

Individual saddle height was adjusted by the knee angle from static upright to elicit a particular knee flexion angles for testing (40º, 30º or 20º) following the next steps:

1. Cyclists pedalled for one minute and then movements were recorded for five crank revolutions. Knee angle with the pedal at the 6 o'clock position was determined for each revolution.

2. Saddle height was then adjusted considering knee angle from static upright to achieve the intended knee flexion angle (40º, 30º or 20º).

3. First step was repeated to ascertain that the knee flexion angle was as intended. If not, steps 2 and 3 were repeated.

Afterwards, cyclists pedaled for 10 minutes in the knee flexion condition in each trial and kinematics was recorded during the last 30 seconds of each trial. For each cyclist and trial, the average of five crank revolutions was used to compute the knee flexion angle when crank arm was at 90º (3 o'clock) and 180º (6 o'clock). These are commonly reported sections of crank cycle to determine body position on the bicycle (Bini et al. 2014). Pedaling cadence was determined from the kinematic data of each pedal revolution.

Statistical Analysis

Data of knee angles were analyzed with a statistics software package (SPSS Statistics 21.0, IBM, Armonk, New York, USA). After confirmation of normal distribution for all variables ($p>0.05$; Shapiro-Wilk test), knee flexion angles with and without adjustment were compared using 2-way ANOVA [adjusted or non-adjusted (2) vs. knee flexion angle target (3) vs. crank position (2)] with Bonferroni post-hoc tests when main effects were observed. Effect sizes (ES) were computed for comparison of mean values using a custom made spreadsheet in Excel (Microsoft Inc., USA). Statistical significance was defined when $p<0.05$ from post-hoc tests and effect sizes were greater than 0.8 (Cohen 1988). Finally, intra-class correlation coefficient (ICC) and typical error were calculated to determine the between-day repeatability of the knee angle from a static upright posture. The following classification for ICC values was used: values 1.00 to 0.81 (excellent repeatability), 0.80 to 0.61 (very good), 0.60 to 0.41 (good), 0.40 to 0.21 (reasonable) and, from 0.20 to 0.00 (poor). Data are reported as mean ± SD in the tables, and in the text with the 95% confidence intervals (95%CI).

Results

Repeatability of the knee angle measurements during static upright taken in different days was classified as very good (ICC=0.73, typical error=0.95º). Table 1 shows differences in saddle height compared to the saddle height used to achieve a knee flexion angle of 30º. Pedaling cadence and knee flexion angle at static upright posture are also shown for each trial.

Table 2 shows knee flexion angles at the 6 and 3 o'clock crank positions for the three knee flexion angles (40º, 30º and 20º), with and without the static upright adjustment. The difference between the adjusted and the non-adjusted knee was independent of the knee flexion angle considered, as no significant interaction (p=0.79) was found between these two factors (knee flexion angle target vs. adjusted or non-adjusted). Differences of 10.6º (p<0.01 and ES>3.0, 95%CI [8.6, 12.6º]) were observed between the dynamic knee flexion angles with and without adjustment considering the static upright position. For the seventeen cyclists, the minimum observed difference was 4.7º and the maximum difference was 19.1º.

Discussion

Our study addressed the influence of adjusting knee flexion angle considering a static upright posture assessment in order to properly determine saddle height in cyclists. Our results showed that the adjustment of the knee flexion angle highlighted a difference of 10.6º (95%CI [8.6, 12.6º]) in comparison to the non-adjusted position. Differences of ~10º between the knee flexion angles (40º, 30º or 20º) resulted in changes of saddle height between 2.6-2.9 cm. Furthermore, knee flexion angle in the static upright position showed a very good repeatability, supporting the use of the static upright posture. These findings illustrates the importance of the suggested adjustment given that the knee angle is related to injury risk and cycling performance (Callaghan 2005; Bini et al. 2011).

The adjustment suggested by the present study highlights the importance of applying this method in kinematic assessment of cycling studies in order to consider individual characteristics of the lower limb anatomy between different cyclists and avoid knee positions previously associated with injury risk. The large variability between cyclists on the individual standing posture, with values between 4.7º and 19.1º, and the very good repeatability of this posture illustrated that the adjustment could be dependent of the cyclists' anatomy, with implications for positioning of markers during kinematic assessments. For this reason, the recommendation for using knee flexion angle measured during pedaling to determine optimal saddle height (Ferrer-Roca et al. 2012) can be improved using individual upright static postures. In the study of Ferrer-Roca et al. (2012), a knee angle between 30° and 40° of flexion was recommended

Table 1. Mean ± SD of the height difference with saddle at 30º, cadence and knee flexion angles at static upright postures in the different tests.

Saddle heights trials	**Difference to saddle height at 30º of knee flexion (cm)**	**Cadence (rpm)**	**Knee flexion angle at static upright posture (º)**
Knee flexion angles	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**
40°	2.9±0.9	79±9	11±4
30°	0	78±7	10±4
20°	-2.6±1.1	77±8	10±5

Table 2. Mean ± SD of knee flexion angle in the 6 and 3 o'clock crank position in the three positions (40º, 30º and 20º), without and with static upright adjustment. Differences were presented with p values and effect sizes. Mean ± SD of the differences in percentage and in degrees were reported. All the differences presented a statistical significance (p<0.05 and ES greater than 0.8).

	Without static upright adjustment	**With static upright adjustment**	**p and ES (without vs. with adjustment)**	**Diff (%) (without vs. with adjustment)**	**Diff (°) (without vs. with adjustment)**
Knee angle - 6 o'clock crank position	**Mean ± SD**	**Mean ± SD**		**Mean ± SD**	**Mean ± SD**
40°	50.4±3.5	40.5±1.1	< 0.01, 4.8	24.9±15.6	-10.9±3.7
30°	39.8±4.0	30.4±0.6	< 0.01, 4.4	35.3±13.6	-10.4±4.0
20°	30.0±4.9	20.5±0.7	< 0.01, 3.7	54.5±27.0	-10.5±5.1
Knee angle - 3 o'clock crank position					
40°	69.5± 5.0	58.6±2.4	< 0.01, 3.1	18.6±6.2	-10.9±3.8
30°	60.8±4.4	50.4±2.0	< 0.01, 3.2	20.6±8.0	-10.4±4.0
20°	52.5±4.6	42.0±2.3	< 0.01, 3.1	25.4±12.9	-10.5±5.1

using dynamic assessment, suggesting that the common range of 25º and 30º should be used in static methods. However, no mention was made in regards to the adjustment of knee angle by the static upright posture. Thus, if we apply the correction proposed in the present study, we found the recommended angle from Ferrer-Roca and colleagues would be between 20° to 30° of flexion, which would have been equivalent to the range commonly used (25º to 30º). Given that the knee angle during static upright posture should influence the interpretation of knee flexion angle during cycling, the proposed method presented in this study may reduce the contrast between recommended optimal and the most used saddle height for cyclists (Iriberri et al. 2008).

Using information from static posture, researchers and bike fitters can avoid opting for an excessively lower saddle height as previously observed (Ferrer-Roca et al. 2012). A large knee flexion angle during pedaling may increase patellofemoral compression forces, which could lead to patellofemoral pain and the development of chondromalacia (Ericson and Nisell 1987; de Vey Mestdagh 1998; Callaghan 2005). Although some studies observed large patellofemoral forces when saddle height decreases (Ericson and Nisell 1987), it is necessary that future studies apply the knee flexion angle adjustment to extrapolate their results to understand the effects on knee joint kinetics. The study of Bini (2012) was performed without applying the adjustment method proposed and he observed higher tibiofemoral anterior force in knee flexion of 44º in comparison with knee flexion between 38º and 33º. If we extrapolate the results of the present study, higher tibiofemoral anterior force would be observed at the knee flexion of 34º, in comparison with knee flexion between 28º and 23º, which could be considered outside and inside, respectively, to the range of 20° to 30° of knee flexion recommended by Ferrer-Roca et al. (2012). Given that, our results suggest that bike fitting and research projects should consider a static upright posture to adjust knee angles and saddle height.

The measurement of the knee flexion angle when the crank arm is at 90º (3 o'clock), although rarely reported, is critical due the larger moment-arm for power production in this position (Coyle et al. 1991; Sanderson and Black 2003). Therefore, optimizing body position on the bicycle by matching the knee flexion angle to the optimal for power production is beneficial for cycling efficiency (Savelberg and Meijer 2003). In that sense, Bini (2012) observed knee angles of ~48º at 3 o'clock (with knee flexion of 33º at 6 o'clock), and angles of ~57º at 3 o'clock in a low saddle height (with knee flexion of 44º at 6 o'clock). Assuming that cyclists show their peak knee extensor torque production at knee flexion angles of 60-70° (Savelberg and Meijer 2003), greater knee flexion angles could be on target for performance. Results from Bini (2012) had a good correspondence with results from the present study, in which we observed angles of ~50° and ~58º at 3 o'clock for knee flexion angles of 30° and 40º at 6 o'clock, respectively. However, knee flexion angles 10º larger (from 25º to 35º at 6 o'clock with the adjusted static posture) may negatively impact cycling economy and anaerobic power given findings of a previous study (Peveler and Green 2011).

The level of significance ($p < 0.01$) and the large effect sizes (ES> 3.0) could support the sample size as enough to draw our conclusion.

In conclusion, the determination of saddle height based on dynamic measures of pedaling without adjusting knee angle for upright standing posture could lead to errors in the definition of knee flexion range during cycling. Considering knee flexion angle from upright standing posture significantly affected the saddle height when determined by knee angle during cycling. The adjustment presented in this study is recommended in order to improve bike fitting methods and comparisons between future cycling studies.

Practical applications

Professional bike fitting services are demanded by a large number of cyclists in order to prevent injuries and improve performance (Disley and Li 2014). Many of these services are based on positioning the cyclist in a suitable knee flexion angles by kinematic motion analysis (Peveler et al. 2012). However, these services probably do not consider the individual characteristics from kinematic analysis, which could be minimized by the static adjustment proposed here. Whenever a correction for each individual standing posture is not taken, a less optimal saddle height would be used. The results of the present study illustrated a high variability between cyclists that showed values between 4.7º and 19.1º for knee flexion angle at upright posture. Because of this, we suggest that the determination of the saddle height should be performed for each cyclist in order to avoid errors due to the variability between cyclists. The present study showed the importance of taking into account the knee static angle in order to properly determinate saddle height.

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Conflict of interest

The authors declare that they have no conflict of interests concerning the content of this study.

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