Angular Position of the Cleat According to Torsional Parameters of the Cyclist's Lower Limb

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Objectives: The aim of this work is to study the relationship of torsional and rotational parameters of the lower limb with a specific angular position of the cleat to establish whether these variables affect the adjustment of the cleat.

Design: Correlational study.

Setting: Motion analysis laboratory.

Participants: Thirty-seven men cyclists of high performance.

Interventions: The variables studied of the cyclist's lower limb were hip rotation (internal and external), tibial torsion angle, Q angle, and forefoot adductus angle.

Main Outcome Measures: The cleat angle was measured through a photograph of the sole and with an Rx of this using the software AutoCAD 2008. The variables were photograph angle (photograph), the variable denominated cleat-tarsus minor angle, and a variable denominated cleat-second metatarsal angle (Rx). The intraclass correlation coefficient for the reliability of the measurements, the Student *t* test performed on the dependent variables to compare side, and the multiple linear regression models were calculated using the software SPSS 15.0 for Windows.

Results: The Student *t* test performed on the dependent variables to compare side showed no significant differences ($P = 0.209$ for the photograph angle, $P = 0.735$ for the cleat-tarsus minor angle, and $P = 0.801$ for the cleat-second metatarsal angle). Values of R and R^2 for the photograph angle model were 0.303 and 0.092 ($P = 0.08$), the cleat/tarsus minor angle model were 0.683 and 0.466 ($P < 0.001$), and the cleat/second metatarsal angle model were 0.618 and 0.382, respectively ($P < 0.001$).

Conclusions: The equation given by the model was cleat-tarsus minor angle = 75.094 − (0.521 × forefoot adductus angle) + (0.116 × outward rotation of the hips) + (0.220 × Q angle).

Key Words: cyclist, lower limb, injuries, clipless pedal, forefoot, cleat position

(*Clin J Sport Med* 2014;0:1–5)

INTRODUCTION

The clipless pedal used nowadays allows a personalized adjustment to the bicycle. One of the most distinguishing characteristics of this type of pedal is that once the cleat is fixed to the pedal, the ensemble has no movement between the parts (only some amount of float in the abduction/adduction degree of freedom), so that the adjustment will determine the relative position of the whole lower limb and the amplitude of movement during the pedaling sequence. Injuries affecting the knee are the most common among cyclists—some 25% of all the nontraumatic lesions suffered.[1] Cyclists of all categories may be affected, but they are most frequent in those of a high level of training. The most frequent locations of overload injury caused in cycling results in femoropatellar pain or knee lateromedial discomfort.[1–3]

Previous research on alterations caused by overloading in racing and road cycling is centered on anatomical imbalances in the lower limb.[1,4,5] Erickson and Nisell[6] describes problems caused by the orientation between the parts of the lower limb generating anomalous load patterns. The knee could be affected if the forces applied to the pedal present anomalous loads.[6] Cyclists' lower limbs function occurs in closed kinetic chain. Femorotibial and femoropatellar joint movements are influenced by feet.

Some studies have focused on quantifying the moments produced in the hip, knee, and ankle joints,[7,8] rather than on the relationship between the torsional and rotational features of the lower limb and a specific position of the cleat. Cyclists' knee problems have been lessened by trial-and-error adjustment of the pedal to reduce knee deviation so far. However, the qualitative nature of the studies limits their application, with no definitive understanding of the relationship between the knee problems and the mechanical adjustments. Therefore, the authors consider it would be interesting to carry out a quantitative evaluation of rider–bicycle interaction to make some preliminary recommendations regarding the clinical effects on injury prevention.[9]

Thus, this study aims at (1) describing a normal angular range for the cleat, taking into account physiological parameters of the lower limb of the cyclist; (2) examining the relationship of the studied rotational and torsional variables of the lower limb of the cyclist with an exact angular position of the cleat in an internal or external orientation; and (3) developing a method to enable adjustment of the cleat. The authors propose the hypothesis that there is a particular adjustment based on a series of anatomical variables of the lower limb, and that such position of the cleat is unique to each cyclist.

Submitted for publication November 20, 2012; accepted September 10, 2013.
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The authors report no conflicts of interest.
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METHODS

This study was performed in the Podiatric Clinical Area of the University of Seville, Spain, during 2008 and 2009. The target population of this work consisted of cyclists who commonly use a clipless road pedal and who practice this sport intensively. The lower limb was established as the unit of study. The sample size was of 74 lower limbs (37 right and 37 left) in 37 participants. Participants gave their written consent to take part in the study, which was approved by the Experimentation Ethics Committee of the University of Seville.

The inclusion criteria were the following:

- Cyclists being older than 20 years (consistent with skeletal maturity).[10,11]
- Not having suffered fractures on the lower limb.
- Not having suffered overuse injuries in the lower limb within the previous year.
- Using Look clipless pedals (Look Cycle International S.A., Nevers, France).
- The cyclists were in the Spanish Cycling Federation.

The variables were recorded using 2 tests: a photograph and a radiograph. For the first one, a Sony Cyber-shot DSC-P120 digital camera (Sony, San Diego, California) was used, with a resolution of 5.1 megapixels, placed on a tripod at a distance from the ground of 1 m, completely vertical to the shoe, which was resting on the ground, and centered on the screen such that the tip and the heel of the shoe exactly fitted the image frame. The anterior–posterior radiographs were made using a Sedecal SPS HF-4.0 X-ray equipment (Buffalo Grove, Illinois). The x-ray image was obtained using 65 kV and 10 mA/s. The inclination of the x-ray tube was 15 degrees to the vertical in the sagittal plane.[12] The tube-to-plate distance was 1 m, according to the criteria of the Committee of Measurements and Terminology of the American Orthopaedic Foot and Ankle Society (AOFAS). All the radiographs were made under weight-bearing conditions, as this is the constant state of the foot in this sport.[13] Because of the radiotransparency of the cleat, it was decided to place a rigid metal element (a nail fastened with an elastic band) on its base to act as a reference in the x-ray image of the angulation of the shoe when fixed to the pedal. This attachment did not affect the integrity or function of the shoe and/or cleat.

After the radiograph had been obtained, it was digitalized using a scanner able to explore images on positive films (Epson Expression 1680 Pro; Seiko Epson Corporation, Nagano, Japan) to create a digital image. The measurements were made on the digital image with the software AutoCAD 2008 (Autodesk Inc, San Rafael, California). The protocol of digitalization and measurement of radiographs by AutoCAD 2008 has been used in earlier studies.[14,15]

The variables studied directly in the lower limb were internal and external rotation of the hip, tibial torsion angle, and Q angle. In the photography, a variable denominated photograph angle was studied. In the x-ray image, the forefoot adductus angle, variable denominated cleat-tarsus minor angles, and a variable denominated cleat-second metatarsal angle were examined. Hip rotations[10,11] were measured using an inclinometer in prone position with the knees flexed 90 degrees and the movement was generated in both lower limbs simultaneously to avoid possible pelvic tilts. Tibial torsion angle[10,11] was also measured using a universal 2-armed goniometer in prone position with knee and ankle flexed 90 degrees, 1 arm of the goniometer being aligned on the external border of the foot and the other on the longitudinal bisection of the thigh. Finally, Q angle was quantified in supine position using the 2-armed goniometer, placing its center on the mid point of the patella, one arm on the anterior tibial tuberosity and the other one on the anterior longitudinal bisection of the thigh. The forefoot adductus angle is formed by the intersection of the longitudinal axis of the second metatarsal with that of the tarsus minor.[16,17] The cleat-tarsus minor angle is formed by the intersection of the forefoot angle with the line described by the base of the cleat.[18] The cleat-second metatarsal angle is formed by the intersection of the longitudinal axis of the second metatarsal with the line described by the base of the cleat (Figure 1).[17,19] For the photograph angle, the method described by Ruby et al[20] was followed, that is, the longitudinal axis of the shoe was taken as the maximum distance from the tip of the shoe to the heel. The angle is formed by the intersection of the perpendicular of this axis with the line formed by the base of the cleat (Figure 2).

Data were analyzed using the software SPSS 15.0 for Windows (SPSS Inc, Chicago, Illinois). The intraclass correlation coefficient for the intraobserver reliability of the

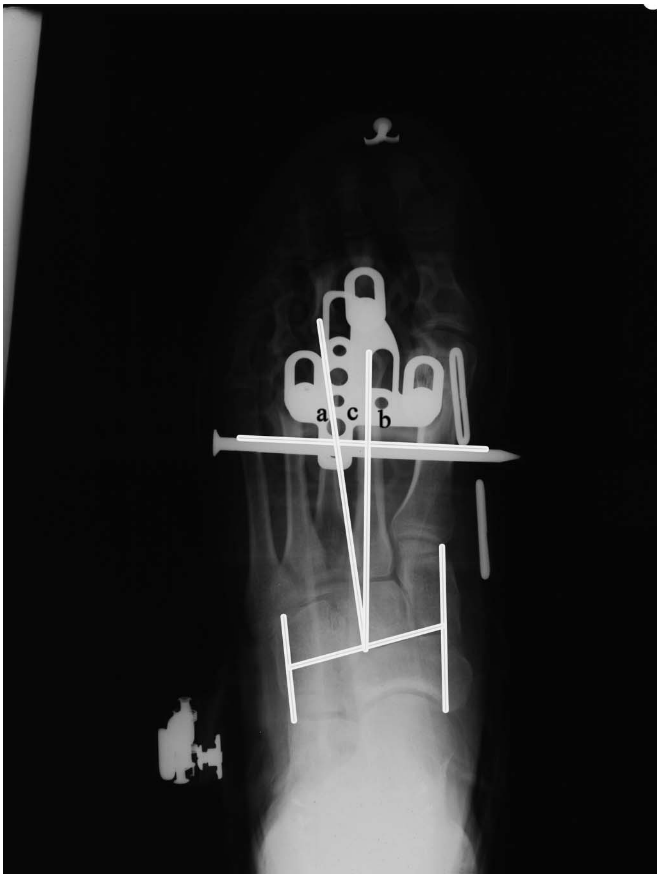

FIGURE 1. X-ray angles. A, cleat-tarsus minor angle. B, cleat-second metatarsal angle. C, forefoot adductus angle.

FIGURE 2. Angle of the cleat on the photograph (arrow).

TABLE. Correlation Coefficient of (a) the Photograph Angle Model, (b) the Cleat/tarsus Minor Angle Model, and (c) the Cleat/second Metatarsal Angle Model

	Nonstandardized Coefficients		95% Confidence Interval	
	B	Standard Error	Lower Limit	Upper Limit
Model a				
Constant	0.025	0.572	−1.115	1.166
Forefoot adductus angle	0.104	0.040	0.024	0.184
Model b				
Constant	75.094	2.553	70.003	80.185
Forefoot adductus angle	−0.521	0.079	−0.678	−0.364
External rotation of the hips	0.116	0.034	0.048	0.184
Q angle	0.220	0.105	0.010	0.430
Model c				
Constant	104.996	2.672	99.668	110.325
Forefoot adductus angle	−0.478	0.083	−0.642	−0.313
External rotation of the hips	−0.119	0.036	−0.190	−0.049
Q angle	−0.212	0.110	−0.432	−0.008

measurements was calculated using 10 randomly chosen cases from the sample, measured 3 times at intervals of 1 week. A statistical purification was made to detect atypical values. The Kolmogorov–Smirnov test was used to check data normal distribution. The results of this test showed a normal grouping of the data, justifying the use of parametric tests. A Student *t* test for independent samples was performed on the variables depending on the lower limb side to test the homogeneity of the sample. Finally, multiple linear regression models were calculated, using as predictive variables the photograph angle, the cleat-tarsus minor angle, and the cleat-second metatarsal angle. The forefoot adductus angle, the tibial torsion angle, the Q angle, the internal rotation of the hip, and the outward rotation of the hip were the predictor variables. The P value was considered significant when lower than 0.05.

RESULTS

Thirty-seven males (74 lower limbs), with a mean age of 35.7 ± 11.5 years, took part in the study. The values of the intraclass correlation coefficient were 0.958 for the photograph angle, 0.860 for the cleat-tarsus minor angle, and 0.848 for the cleat-second metatarsal angle ($P < 0.001$). Values were significant, and the method of measurement was considered reliable.

The Student *t* test performed to compare side (right and left) showed no significant differences ($P = 0.209$ for the photograph angle, $P = 0.735$ for the cleat-tarsus minor angle, and $P = 0.801$ for the cleat-second metatarsal angle).

Values of R and R^2 for the photograph angle model were 0.292 and 0.085, respectively ($P = 0.012$). The multiple linear regression procedure (Table) yielded the following equation for the determination of the cleat position: photograph angle = 0.025 + (0.104 × forefoot adductus angle).

Values of R and R^2 for the cleat/tarsus minor angle model were 0.683 and 0.466, respectively ($P < 0.001$). The multiple linear regression procedure (Table) yielded the following equation for the determination of the position: cleat-tarsus minor angle = 75.094 − (0.521 × forefoot adductus angle) + (0.116 × outward rotation of the hips) + (0.220 × Q angle).

Values of R and R^2 for the cleat/second metatarsal angle model were 0.618 and 0.382, respectively ($P < 0.001$). The multiple linear regression procedure (Table) yielded the following equation for the determination of the position: cleat-second metatarsal angle = 104.996 − (0.478 × forefoot adductus angle) − (0.119 × outward rotation of the hips) − (0.212 × Q angle).

DISCUSSION

The main aim of this study was to determine the effect of the rotational and torsional configuration of the lower limb and its influence on the position of the cleat. The authors used some of the variables described by Sanner and O'Halloran,[21] such as hip rotations, tibial torsion angle, and Q angle—necessary to determine the cleat position—together with the forefoot adductus angle. Values of the variables were found to be within the normal ranges reported in other studies by Staheli,[22] Staheli et al,[11] D'Amico and Rubin,[2] Gelberman et al,[23] and Munuera et al.[14,18]

Ruby and Hull[24] quantified the rotation of the cleat and obtained a value of 3 ± 2 degrees, different from the one obtained in the present work (1.44 ± 0.17 degrees). Despite the method used being the same, the authors believe that shoe design could affect the measurement result. In the aforementioned study, the intraclass correlation coefficient was not used to check the reliability of the measurement. In the present works, this coefficient was applied, with results indicating that the methods of measurement were reliable. Farber et al[25] demonstrated that the use of a digital system to measure certain angles on radiographs was valid and improved the interobserver and intraobserver reliability over that of the analogical technique using tractograph and pencil.

Independently of the method of quantifying the rotation of the cleat, the values indicated a posture of the lower limb in external rotation or, at least, very close to neutrality. When calculated from the photograph angle, the mean value was 1.44 ± 0.17 degrees, using the cleat-tarsus minor angle it was 75.93 ± 0.42 degrees, and the cleat-second metatarsal angle value was 90.44 ± 0.41 degrees (Figure 1). It was observed that all participants presented these values of external rotation in all the variables. Thus, the cleat position is in external rotation and, when the shoe is fixed, the cleat aligns the lower limb in a posture that is outward or close to neutral.

Femoropatellar instability, Osgood-Schlatter disease, and osteochondrosis dissecans are increasingly seen in patients with increased external tibial torsion.[2] More specifically, in the cycling activity, determining a wrong position of the cleat would generate a functional variation of the tibial torsion angle. It should not be forgotten that torsion is nothing more than a static parameter offering a starting point for tibial rotations taking place during pedaling.[26] The present study yielded a mean external tibial torsion of 17.33 degree, which could increase by a maximum of 1.67 degree with the parameters considered nonharmful (using the variable cleat-second metatarsal angle), so that increased outward positions of the cleat would vary the starting position of tibial rotation.

Davis and Hull[27] studied the moments obtained on the pedal, making certain alterations in it, such as rotations of ±5 degrees in the transverse plane (F_z) from a neutral point. They found variations in moments, although without constant patterns of change between cyclists. In the present study, depending on the method of quantifying the angulation, it was found maximum values between 1.67 and 1.70 degrees (cleat-second metatarsal angle and cleat-tarsus minor angle, respectively), indicating that the alterations made by Davis and Hull[27] did not have great consequence in the pursuit of significant results. A correct application of the force on the pedal is a proper indicator of the muscular action of the whole lower limb.

The fact that the 2 regression models with highest significance (the second one and the third one) coincide in the independent variables after a stepwise linear regression procedure is noteworthy, as it rules out the variables less determinant for the model. Thus, it can be stated that, among the characteristics of the lower limbs measured, external rotation of the hips, forefoot adductus angle, and Q angle are important in the adjustment of the cleat. These data contradict those obtained by Sanner and O'Halloran,[21] who stated that the cleat should be adjusted so that the foot is angled in the transverse plane depending on the anatomy of the cyclist, with the malleolar torsion presenting the greatest effect on the adjustment; however, in all the models calculated in this study, the tibial torsion angle was redundant.

The position of the cleat can vary the Q angle, altering the position of the anterior tibial tuberosity, the point of insertion of the patellar tendon. Thus, very outward positions of the cleat will increase the value of the Q angle and vice versa. A recent study suggested that both an increase and a decrease in the Q angle generate an increase in the maximum pressure of femoropatellar contact and thus they should be considered important etiological factors in chondromalacia.[2] This notion is corroborated in the study of Sanderson et al,[28] who stated that higher medial loads on the foot could be due to increased tibial torsion.[29]

These results suggest that the proposed hypothesis of the study could be valid, and the null hypothesis may be rejected, so that the cleat could be adjusted for each lower limb taking into account particular characteristics of the cyclists. Rotational adjustment of the cleat would require quantification of the external hip rotation, the Q angle, and the forefoot adductus angle.

The photograph angle model results as the most practical model because it does not require any radiograph to take measurements. However, values of R and R^2 obtained in this studied should be improved in future research to use this model.

An obvious question that might be raised after these results is whether customizing cleat angular positioning will help reduce lower extremity injuries in cyclists. As the present study does not address this issue, the authors think that future follow-up studies could help address the clinical implications of the anatomic cleat positioning.

CONCLUSIONS

The variables presenting the strongest correlation coefficient in the linear regressions were external rotation of the hips, forefoot adductus angle, and Q angle. The results for cleat position varied depending on the method of quantifying it, but this position was always externally rotated. The normal values of rotation of the cleat related to physiological parameters of the lower limb were 1.44 ± 0.35 degrees measured with the photograph angle, 75.93 ± 0.53 degrees with the cleat-tarsus minor angle, and 90.44 ± 0.36 degrees with the cleat-second metatarsal angle. The exact position of the cleat based on the rotational and torsional parameters of the lower limb studied could be determined from the following equation ($P < 0.001$):

$$\begin{aligned}\text{Cleat-tarsus minor angle} = 75.094 \\ - (0.521 \times \text{forefoot adductus angle}) \\ + (0.116 \times \text{outward rotation of the hips}) \\ + (0.220 \times \text{angle Q}).\end{aligned}$$

PRACTICAL IMPLICATIONS

- Cyclists may have a problem when the cleat is replaced, because it is difficult to place in the same position. When the degrees of cleat position are known, the new cleat can be placed in the same position.

- Cyclists may have a risk of injury when cleats are improperly positioned. Although it has not been studied implication on injuries, the most comfortable position of the cleat in healthy elite cyclists has been recorded related to certain lower limb parameters. The authors think that, with the results of the regression models, the cleat position could be modified more accurately should cyclists suffer from lower limb injuries.
- An outcome from this research was a patent model (N°: ES1078023) of a rotational-adjustment cleat for road clipless pedals. This device allows a rotational cleat adjustment under the shoe according to torsional lower limb parameters of each cyclist. Further research using this device will let us a proper knowledge of cyclists' injuries related to rotational cleat adjustment.

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