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The Effect of Changes in Bicycle Pedal Width on the Kinematics of Segments and Joints of Lower Extremity: Analysis of the Risk of Knee Overuse Injuries with Pedaling (A Cross-sectional Study)

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Original Article

Abstract

Introduction: Pain and overuse injuries of the knee joint is prevalent among cyclists. The bicycle adjustment in accordance with the cyclist's body mechanics is a common way to reduce the risk of overuse injuries. The aim of this study is to investigate the effect of changes in bicycle pedal width on the kinematics of segments and joints of lower extremity and its association with the risk of knee overuse injuries during pedaling.

Materials and Methods: 10 professional cyclists of Shiraz City, Iran, pedaled at 100% of maximum power output with four different pedal widths (Q0: conventional pedal width, Q1: Q0 + 1cm, Q2: Q0 + 2cm, and Q3: Q0 + 3cm). The angle of the lower extremity segments and joints was recorded three dimensionally for thirty seconds during pedaling in each pedal width by myoMotion system. The minimum, maximum, and mean angles and range of motion (ROM) variables of hip and ankle (sagittal plane), knee joint (sagittal and frontal planes), and thigh and shank angles in the frontal plane were calculated. One-way repeated measures analysis of variance (ANOVA) and Bonferroni post-hoc test were used to identify significant changes.

Results: The statistical results showed that changes in the pedal width had a significant effect of on minimum ($P = 0.035$), maximum ($P \leq 0.042$), and mean ($P \leq 0.020$) of shank abduction/adduction and minimum ($P = 0.015$), mean ($P \leq 0.022$), and ROM ($P \leq 0.018$) of ankle dorsiflexion/plantar flexion, while changes in the pedal width had no significant effect on other kinematics parameters.

Conclusion: The results indicate that pedal width of Q1 has the highest potential to lower the risk of knee injury and provide increased efficiency whilst cycling; Still, the standard pedal width of road bikes (Q0) seemed not appropriate for professional Iranian cyclists since it increases the risk of knee joint overuse injuries.

Keywords: Bicycle; Pedal width; Kinematics; Knee overuse injury

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Introduction

Riding a bicycle is a professional and recreational sport that, in addition to being widely used as a vehicle in developed countries, is also used to rehabilitate injuries. Pedaling with proper resistance can be a good rehabilitation exercise for anterior cruciate ligament (ACL) injury (1). As the time the ordinary and professional people use bicycles, the prevalence of the associated overuse injuries increases as well (2). The highest overuse injury has been reported for the knee joint (about 23-50%) (3). Inexperience (4), prolonged pedaling (5), and improper bike adjustment based on the cyclist's anatomy (6) have been reported as possible causes of knee pain and injury. Increased knee joint abduction and ankle joint dorsiflexion have been reported in individuals with knee pain compared to those

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without pain (7). The configuration of the bicycle affects the cyclist's body and limb position; if the bicycle saddle height is too low, the maximum knee flexion increases and increases the risk of the knee joint overuse and the patellofemoral inflammation (8). Additionally, adapting the bicycle to the cyclist's body type is one of the important factors affecting the amount of the force produced by the muscle and, consequently, the load applied to the joints (9).

Bicycle adjustment is performed on the basis of the body type of people in static and dynamic states (10,11). In the static mode, the bike is adjusted to the anthropometric dimensions of the cyclist's body (12,13), but the dynamic adjustment is better than the static mode; Because the kinematics of individuals while riding a bicycle is different from the static state (10). Many factors do not seem to be taken into account in body type, which affect the position of the body and limbs of the cyclist and, hence, the biomechanics of movement. These factors include differences in the width of the pelvis or the Q-angle, which can cause dynamic valgus of the knee, as well as differences in the effective force exerted on the pedal while pedaling. Differences in pelvic width and Q angle among different individuals, especially different genders, have been demonstrated in previous studies (14). This difference in individuals can cause a difference in the direction of the lower limb during pedaling and increase adduction or abduction of the knee, increasing the risk of injuries to the knee joint during pedaling (7,15-18).

One of the ways to adjust the alignment of the lower limb in order to optimize the applied force and reduce knee adduction while pedaling is to choose the right pedal factor (Q-factor) for each person to fit the width of the pelvis or the Q-angle (17,18). However, this has not been well explored, and the question is, "Can changing the width of the pedals affect the kinematic values of the lower limb associated with the risk of the knee overuse injury?" Therefore, the present study is conducted with the aim to investigate the effect of four different pedal widths on changes in the angles of the segments and joints of the lower limbs during pedaling with 100% of the athlete's strength.

Materials and Methods

This study was conducted at the location of Fars Province Cycling Board in Hafezieh Stadium, Shiraz, Iran. According to a call by the head of the Fars Province Cycling Board, 10 male and female semi-professional road cyclists participated voluntarily in this semi-experimental cross-sectional study. The subjects had three cycling sessions per week and, according to their response to the researcher-made questionnaire, they had no lower limb abnormalities or lower limb or pelvic injuries during the past six months, and completed a consent form and personal information to participate in the study. In the first session, after the subjects entered the test site, the height and weight of each subject were measured. Then, the height of the bicycle saddle for each subject was adjusted so that when the pedal was at the lowest point, the knee flexion angle was 25 degrees (19). In the next step, in order to determine the maximum aerobic power, the subject got on a bicycle connected to an ergometer (TechnoGym, German) and started pedaling with a load of 1 W/kg of his/her weight. The load was increased by 35 and 25 W after every three minutes respectively for male and female subjects until the subject reached exhaustion. The pedaling speed was controlled in the range of 90-95 round per minute (rpm) and the test was completed when the pedaling speed reached less than 85 rpm (20).

During the test for calculating the maximum aerobic power, the pedal width was set to 150 mm, which is the standard value of the pedal width of road bikes. The maximum output power (PO_{peak}) was calculated from the percentage of time (t%) and the output power (PO_{final}) of the last step according to the following equation (20) (Equation 1).

Equation 1. Calculation of the maximum output power when pedaling on a stationary bicycle

$$t\% \times PO_{final} = PO_{peak}$$

48 hours after determining the maximum output power, the kinematic evaluation of the lower limb joints while pedaling with different pedal widths was performed using the myoMOTION three-dimensional analysis system (myoMOTION, Noraxon, USA) at a frequency of 200 Hz. The subjects were asked not to have done severe cycling training in the past 24 hours. They wore cycling shoes that were locked on the bicycle pedals. After mounting the inertial sensors and accelerometers on the feet, shanks, thighs, and pelvis of the subject according to the instructions given by Noraxon Company, USA, calibration was performed (21). After warming up for five minutes at a power rate of less than 150 W, the subjects pedaled for 40 seconds with the standard pedal width (Q0) and 100% of their power, and in the middle 30 seconds, their lower limb three-dimensional kinematic data were recorded. To ensure that fatigue did not affect the results, each 40-second effort was accompanied by 10 minutes of complete rest while

sitting on a comfortable sofa. During the rest, the pedal width was increased to 1 (Q2), 2 (Q3), and 3 cm (Q4) by the washers and screws prepared, and again, the kinematic information was recorded in 30 seconds. The kinematic data of 20 pedaling cycles were separated for each subject using knee angle. The raw data were filtered using a fourth-order Butterworth low-pass filter with a cut-off frequency of 8 Hz and normalized to 100 data points, and then, for each data point, the average of 20 cycles was calculated. The maximum, minimum, range of motion (ROM), and mean flexion of the hip, knee, and ankle joints (sagittal plane) and abduction of thigh, shank, and knee joint (frontal plane) were calculated and compared in different pedal widths. With three successful recordings for each pedal width, the total data collection process for each subject took about 45 minutes which was performed during a full day. Data extraction was performed by coding in MATLAB R2018a software (MathWorks Ink., USA).

Data distribution was analyzed by Shapiro-Wilk test, and comparison of the effect of the pedal width change was performed with repeated measures analysis of variance (ANOVA) and Bonferroni post hoc test in SPSS software (version 16.0, SPSS Inc., Chicago, IL, USA).

Results

The demographic characteristics of the 11 subjects included a mean age of 27.41 ± 5.12 years, height of 168.68 ± 3.48 cm, weight of 64.95 ± 5.19 kg, body mass index (BMI) of 22.42 ± 3.26 kg/m^2, and mean cycling experience of 4.47 ± 2.61 years.

The angles of the lower limb joints on the sagittal plane while pedaling under the four pedal width conditions are presented in table 1.

The angles of the thigh and shank segments and the joints of the lower limbs on the frontal plane while pedaling in the four pedal width conditions are presented in table 2.

Among the variables measured, the effect of changing the pedal width was significant only on the minimum ($P \leq 0.035$), maximum ($P \leq 0.042$), and mean ($P \leq 0.020$) abduction of the shank segment and variables of the minimum ($P \leq 0.015$), ROM ($P = 0.022$), and mean ($P \leq 0.018$) ankle flexion. The post hoc test results indicated a significant difference between the pedal width Q0 and the three pedal widths Q1, Q2, and Q3 in the minimum ($P \leq 0.049$, $P \leq 0.043$, and $P \leq 0.024$), maximum ($P \leq 0.048$, $P \leq 0.041$, and $P \leq 0.033$), and mean ($P \leq 0.027$, $P \leq 0.043$, and $P \leq 0.022$) shank abduction angles and a significant difference between the pedal width Q0 and the three pedal widths Q1, Q2, and Q3 in the minimum ankle flexion ($P \leq 0.048$, $P \leq 0.027$, and $P \leq 0.004$). Moreover, in the ankle flexion ROM, there was a significant difference between the pedal width Q2 and the pedal widths Q0, Q1, and Q3 ($P \leq 0.020$, $P \leq 0.029$, and $P \leq 0.042$) as well as between the pedal width Q0 and the two pedal widths of Q2 and Q3 ($P \leq 0.037$ and $P \leq 0.025$) in the mean ankle flexion angle. The effect of changing the pedal width on other variables and measured kinematic angles was not significant.

Table 1. Mean ± standard deviation (SD) of the measured variables of lower limb joint angles on the sagittal plane in different pedal widths

Joint	Variable (°)	Pedal width			
		Q0	Q1	Q2	Q3
Hip	Joint minimum flexion	40.2 ± 10.2	39.9 ± 11.4	40.4 ±12.3	37.7 ±12.9
	Joint maximum flexion	89.8 ±9.2	94.1 ± 5.6	93.3 ± 6.2	94.0 ± 7.7
	ROM of the joint flexion	53.1 ± 7.6	52.8 ± 7.4	53.8 ± 6.4	53.4 ± 7.0
	Joint mean flexion	62.7 ± 9.9	66.3 ± 7.0	66.0 ± 7.9	66.4 ± 7.9
Knee	Joint minimum flexion	35.5 ± 20.8	33.0 ±14.9	32.6 ± 14.4	31.5 ± 16.1
	Joint maximum flexion	118.2 ± 14.9	117.1 ± 9.1	115.8 ± 8.5	114.9 ± 7.8
	ROM of the joint flexion	82.7 ± 7.2	84.0 ± 7.1	83.2 ±7.2	83.3 ± 10.1
	Joint mean flexion	78.8 ± 7.8	77.4 ± 7.4	76.1 ±7.7	75.9 ± 9.3
Ankle	Joint minimum flexion	$^{+\#\dagger}$-22.5 ± 12.9	*-25 ± 13.6	*-29.9 ± 13.8	28.3* ± 12.9
	Joint maximum flexion	6.5 ± 6.2	3.2 ± 5.4	3.7 ± 5.6	2.9 ± 7.8
	ROM of the joint flexion	$^{\#}$ 29.0± 11.8	$^{\#}$ 28.5± 12.2	$^{*+\dagger}$ 33.7± 11.5	$^{\#}$ 31.3± 15.1
	Joint mean flexion	$^{\#\dagger}$-7.2 ± 6.3	-9.4 ± 7.1	*-12.0 ± 7.8	*-11.6 ± 6.3

* Significant difference with pedal width Q0; $^{+}$ Significant difference with pedal width Q1; $^{\#}$ Significant difference with pedal width Q2; † Significant difference with pedal width Q3

Table 2. Mean ± standard deviation (SD) of the measured variables of the angles of the segments and joints of the lower limb on the frontal plane in different pedal widths

Joint/segment	Variable (°)	Pedal width			
		Q0	Q1	Q2	Q3
Thigh	Segment minimum abduction angle	-40.9 ± 24.0	-26.2 ± 24.5	-31.9 ± 19.7	-30.6 ± 21.7
	Segment maximum abduction angle	3.4 ± 5.5	6.8 ± 8.8	3.2 ± 6.2	3.0 ± 5.2
	Segment abduction ROM	44.3 ± 25.3	33.0 ± 16.8	35.1 ±16.5	33.6 ± 19.2
	Segment mean abduction angle	-9.4 ± 11.2	-5.9 ± 14.2	-10.2 ± 10.5	-10.4 ± 11.2
Knee	Joint minimum abduction angle	-6.9 ± 7.8	-4.1 ± 6.9	-4.7 ± 7.0	-4.3 ± 6.5
	Joint maximum abduction angle	3.1 ±6.7	4.5 ±5.2	4.7 ± 6.1	3.9 ±5.3
	Joint abduction ROM	10.0 ± 4.2	8.6 ± 2.6	9.4 ± 2.0	8.3 ± 2.4
	Joint mean abduction angle	-1.0 ± 6.7	0.51 ± 6.7	0.91 ± 7.3	0.6 ± 6.5
Shank	Segment minimum abduction angle	$^{+\#\dagger}$-3.4 ± 7.2	*-6.8 ± 8.0	*-7.5 ± 7.8	*-8.7 ± 7.4
	Segment maximum abduction angle	$^{+\#\dagger}$ ۶,۴± 9.4	* 2.6± 6.8	*3.2 ± 11.2	*2.4 ± 10.1
	Segment abduction ROM	9.9 ±5.0	9.4 ± 5.1	10.8 ± 6.6	11.1 ± 5.6
	Segment mean abduction angle	$^{+\#\dagger}$ 1.8±7.2	*-1.5± 6.0	*-2.0 ± 8.4	*-2.9 ± 7.5

*Significant difference with pedal width Q0; $^{+}$ Significant difference with pedal width Q1; $^{\#}$ Significant difference with pedal width Q2; † Significant difference with pedal width Q3

Discussion

The aim of this study was to determine the effect of pedal width change on the kinematics of the lower limb segments and joints associated with the risk of knee joint overuse injury during pedaling. Accordingly, the angles that increase the risk of the knee joint overuse injury were analyzed. Therefore, the knee joint abduction in the frontal plane was reported and the angles of the thigh and shank segments were selected based on the probability of the knee joint overuse injury. Among the kinematic variables measured, the effect of changing the pedal width was significant only on the shank segment angles in the frontal plane and the ankle joint in the sagittal plane. With increasing the pedal width, the maximum and minimum values of the shank abduction/adduction increased and decreased, respectively; this finding actually meant a decrease and an increase in the shank adduction and abduction, respectively.

As the pedal width increased from Q1 to Q2 and 3Q, the shank abduction increased. Another variable in the shank abduction, which was significantly different between the pedal width Q0 and the other three pedal widths, was the mean shank abduction angle, which had the smallest value (1.5 degrees) in the Q1 pedal width and was closer to zero compared to the Q0 pedal width as well as the two other widths. Considering a piston-like motion for the thigh and shank segments, these two segments should not have much internal-external motion; as it increases the Varus-Valgus load on the knee and also reduces the effective force on the pedal (22).

Of the four pedal widths, at pedal width Q1, the angle of the shank segment on the frontal plane was closer to zero in comparison to the other three pedal widths; therefore, the least internal-external movement of the lower limb was achieved using this pedal width. By reducing the pedal width from Q1 to Q0, increasing the shank adduction is likely to increase the Varus loads on the knee, and increasing the pedal width from Q1 to Q2 and Q3 has led to increasing the shank abduction and Valgus loads on the knee, reducing the effective force applied to the pedal on both cases.

In the pedal width Q0, the abduction of the knee joint was greater and its angular variations were approximately between -7 and 3 degrees; Therefore, it seems that at this pedal width, the knee joint would be exposed to larger Varus loads. In the other three pedal widths, however, changes in the angle of the knee joint on the frontal plane were approximately between -4 and 4 degrees, indicating that the Valgus and Varus loads on the knee joint are more evenly distributed than the Q0 pedal width. Among these three pedal widths, the knee joint seems to have had the least internal-external movement in Q1; because it has the smallest mean and ROM values in this pedal width.

Another important result of this study is the significant effect of changing the pedal width on the dorsiflexion angles of ankle. The results of the post hoc test mainly showed a significant difference in the measured variables of the dorsiflexion angles of the ankle between the pedal width Q0 and the other three pedal widths. The minimum and maximum ankle dorsiflexion values indicate that the pedal width Q0 was associated with higher dorsiflexion compared to the other three pedal widths. Increased ankle dorsiflexion has been reported in cyclists with knee pain compared to painless cyclists (15). Therefore, it is likely that the pedal width Q0 will put the cyclists to the higher knee joint injuries than the other three pedal widths by increasing the ankle dorsiflexion. The ankle dorsiflexion ROM values show that with increasing the pedal width from Q0 to Q1, the ROM decreases and with increasing the pedal width from Q1 to Q2 and Q3, the ROM of the ankle joint increases.

Regarding femoral abduction and adduction movement, as for the knee joint, no significant difference was observed among the four pedals. However, the remarkable point was the very high abduction of the thigh segment in the pedal width of Q0 in the pedaling cycle compared to the other three pedal widths (about 22.5-35%). Excessive abduction of the thigh relative to the patella can reduce the contact area in the patellofemoral joint and, in the long run, cause pain and injury in this joint (23). Additionally, excessive abduction of the thigh segment increases the abduction of the knee joint. The smallest maximum abduction value in the thigh segment was associated with the Q1 pedal width as about 25 degrees (Table 2). Given the above, especially the results of angular changes in the shank segment and ankle dorsiflexion, which were reported to be significant, it seems that Q1 is the most suitable pedal width to reduce injuries caused by the knee joint overuse; Because in this pedal width, the shanks and femur have the least internal-external movement and the distribution of the Valgus-Varus loads applied on the knee joint will be more balanced. However, the results suggested that the use of pedal widths smaller than and greater than Q1, respectively, can increase the risk of overuse injuries due to increased Valgus-Varus loads on the knee joint among cyclists.

Limitations

One of the limitations of the present study was the lack of measurement of anthropometric characteristics such as pelvic width or Q angle of the subjects in this study. In their study, Fang et al. reported that 7 subjects showed abduction torque (12 to 6 p.m.) and 11 showed adduction torque at the knee joint during the pedaling power phase (16). The main cause of this discrepancy may be related to the direction of the pedal reaction force towards the knee joint. The anthropometric characteristics of individuals, such as pelvic width, Q angle, or hip rotation, can affect the direction of the lower limb during pedaling and cause differences in the direction of the pedal reaction force (16). For example, the lower limb of a person with a smaller pelvic width or Q angle may be in the right direction at pedal width Q0, but in the case of a person with a larger pelvis width or Q angle, the pedal width Q1 may put his lower limb at the right direction. Accordingly, the small sample size and measurements on women and men in a group can affect the generalizability of the results for male or female athletes alone; because a significant difference in pelvic width and Q angle has been proven in the two genders. Another limitation of this study was the lack of kinematic measurement of joints and limbs in different power rates. Changing the pedal width may have different effects on different workloads (different power rates) (16,24,25). Another limitation of this study was the lack of electromyography (EMG) measurement of the lower limb muscles. Recording of the force and torque data from the pedal required using pedal force recording devices that are not available in Iran, and therefore, performing inverse dynamics and torque calculations was not possible. Kinetic analysis, along with kinematics, can provide researchers with more accurate information on the potential knee overuse injury.

Recommendations

Future studies are recommended to find the right pedal width depending on the pelvis width or the size of the Q angle. Measuring the Q angle of individuals and dividing them into groups with small, large, and normal Q angles, and performing a similar test can determine the use of the appropriate pedal width for each group. Since only 100% power was considered in this study, it is recommended to conduct similar studies on different pedaling powers. Furthermore, MG studies combined with kinematics give a better understanding of the effect of changing the pedal width on muscle activation and consequently the biomechanics of the lower extremities. It is suggested that in future investigations, the anthropometric characteristics of the lower limbs of cyclists such as pelvic width and Q angle be measured and the effect of changing the pedal width to the anthropometric characteristics of individuals be determined. The trend of Q angle changes was not considered in this study, so it can be considered in future studies. Additionally, the effect of reducing the pedal width can be the subject of further studies.

Conclusion

In summary, the results of the present study revealed that the use of different pedal widths can affect the kinematics of the lower limbs and joints, and the different pedal widths should be used with caution. However, because the pedal width Q1 (conventional pedal width plus 1 cm) was able to reduce the kinematic risk factors for knee joint pain in the subjects, the use of this pedal width is recommended for road cyclists. The findings also suggested that at this pedal width, the shank and thigh segments and the knee joint have the least internal-external movement; thus, the lowest Valgus-Varus loads are applied to the knee joint.

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Authors' Contribution

Ali Abbasi: study design and ideation, attracting financial resources for the study, support, executive, and scientific study services, providing study equipment and samples, data collection, analysis and interpretation of results, specialized statistical services, manuscript preparation, specialized manuscript evaluation in terms of scientific concepts, approval of the final manuscript to be submitted to the journal office, the responsibility of maintaining the integrity of the study process from the beginning to the publication, and responding to the referees' comments; Mohammad Amin Mohammadian: study design and ideation, analysis and interpretation of results, specialized statistics services, manuscript preparation, specialized evaluation of the manuscript in terms of scientific concepts, approval of the final manuscript to be submitted to the journal office, the responsibility of maintaining the integrity of the study process from the beginning to the publication, and responding to the referees' comments; Shahram Abbasi: study design and ideation, providing study equipment and samples, data collection, analysis and interpretation of results, manuscript preparation, specialized evaluation of the manuscript in terms of scientific concepts, approval of the final manuscript to be submitted to the journal office, the responsibility of maintaining the integrity of the study process from the beginning to the publication, and responding to the referees' comments; Hadi Bashafaat: study design and ideation, support, executive, and scientific study services, providing study equipment and samples, data collection, manuscript preparation, specialized manuscript evaluation in terms of scientific concepts, approval of the final manuscript to be submitted to the journal office, the responsibility of maintaining the integrity of the study process from the beginning to the publication, and responding to the referees' comments.

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Conflict of Interest

The authors declare no conflict of interest.

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