한국운동역학회지, 2004, 제14권 1호, pp. 173-182
Korean Journal of Sport Biomechanics
2004, Vol. 14, No. 1, pp. 173-182

Muscle Activity of Cycling Movements at Different Pedal Shaft Widths

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국문초록

사이클 운동시 페달 샤프트 너비에 따른 근육 활동 비교

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본 연구의 목적은 사이클 운동 시, 3가지 다른 길이의 페달 샤프트 (표준형, 5.08 cm, 10.16 cm)가 근육활동에 미치는 영향을 근전도 측정을 통해 비교 분석하는데 있다. 사이클링을 활동적으로 하는 여학생 5명을 피험자로 선택하여 대퇴지근 (RF), 외측광근 (VL), 내측광근 (VM), 대퇴이두근 (BF)을 표면전극을 사용하여 관찰하였다. 자료 분석을 위해 두 대의 S-VHS 카메라 (Panasonic Digital 5000)를 사용하여 사이클링 동작을 촬영하였다. 연구의 목적을 위해 각 조건에 대한 표준화된 평균 및 최대 근전도치가 계산되어졌다. 각각의 변인에 대해 페달 샤프트의 길이에 따른 근전도치의 차이점을 분석하기 위해 반복측정에 의한 일원변량분석을 사용하였으며, 통계적 유의성이 있을 경우 Newman-Keuls 사후검증을 실시하였다.

이 논문은 2003년도 경북대학교의 연구비에 의하여 연구되었음
투 고 일 : 2004년 2월 15일 접수
심 사 일 : 2004년 3월 8일
심사완료일 : 2004년 4월 3일
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일반적으로 5.08 cm 길이의 페달 샤프트를 사용했을 경우 표준형의 페달 샤프트와는 다르게 모든 하지근의 적분 근전도치가 줄어드는 것으로 나타났다. 페달 샤프트의 길이가 길어짐에 따라 외측광근의 적분 근전도치가 통계적으로 유의하게 낮게 나타났고, 5.08 cm 길이에서 대퇴이두근의 적분 근전도치가 통계적으로 유의하게 낮게 나타났다. 페달 샤프트 길이에 따른 최대 근전도치의 통계적 유의성을 찾을 수 없었지만, 일반적으로 5.08 cm 길이의 페달 샤프트를 사용할 때 최대 근전도치가 가장 낮게 나타났다.

본 연구의 결과, 페달 샤프트의 길이가 하지근의 활동정도와 형태를 변화시킨다는 것을 알 수 있었으며, 하지관절의 부하에 영향을 미치는 것으로 사료되어진다. 이에 따라, 개인의 해부 구조학적인 면을 고려한 페탈 샤프트의 길이 조절은 효율적이며 안정적인 사이클링 동작을 수행하는데 많은 도움이 될 수 있을 것이다.

KEY WORDS : CYCLING, PEDAL SHAFT WIDTH, MUSCLE ACTIVITY

Ⅰ. Introduction

The bicycle was the first machine to be mass-produced for personal transportation and was a prominent figure in the early development of the automobile. A remarkably efficient machine both structurally and mechanically, the bicycle continues to offer distinct advantages as a means of personal transportation. In the sport of cycling, both recreational enthusiasts and competitors desire to maximize their performance. In order to provide for better performance, the bicycle must transmit power efficiently, must minimize rolling resistance, and must be the minimum weight in order to reduce the effort of pedalling uphill.

Cycling has received much attention from biomechanics researchers in recent years. Previous observations in the research literature have focused on EMG activities while cycling against varying degrees of resistance at constant pedalling rate (Houtz and Fisher, 1959), saddle heights and loads (Desipres, 1974), loads and pedalling frequencies (Goto et al., 1976), speeds (Miller and Seireg, 1977; Suzuki et al., 1982), RPMs, work loads, RPMs, saddle heights, foot positions, and toe-clips (Ericson et al., 1985), gear ratios, shoes, and seat heights (Jorge and Hull, 1986). However, no attempts have been made to study muscle activity during cycling at different pedal shaft widths. Because the general objective of cycling is to reach an end point as effectively as possible, understanding interfaces between the rider and bicycle is critical. Propulsion of a bicycle via pedalling action of the legs is caused by contraction of the leg muscles. Understanding which muscles are active while pedalling and the forces being developed by the muscles is very important. A thorough understanding of the muscle activity process could very well lead to improvements in efficiency. In this study, EMG activities during cycling were investigated under conditions of different pedal shaft widths. It is clear that the lower limb muscle stresses may be determined with good accuracy directly from EMG activity. The results of this study will provide useful information to design and build bicycles for optimum performance and comfort. This understanding could lead to either elimination or amelioration of overuse injuries in the knee incurred from the pedalling activity.

Ⅱ. Procedures

1. Subjects

Five female subjects were asked to participate in this study. All of the subjects were experienced recreational cyclists. Each subject was familiarized with the experimental protocol and signed an informed consent statement, as required by the University Guidelines for the Protection of Human Subjects. The men physical characteristics of the subjects sample were: age, 25±2.35 yr; height, 165±7.16 cm; weight, 61.8±12.01 kg; trochanteric leg length, 85.3±4.60 cm.

2. EMG Recordings

To obtain information of muscular activity of each subject, the silver chloride surface electrodes were placed over the muscle bellies of vastus medialis (VM), rectus femoris (RF), vastus lateralis (VL), and the biceps femoris (BF). The ground electrode was placed on the anterior tibial shaft. The surface electrode leads attached to two P15 Grass Preamplifiers were used to gather the EMG activity signals. The preamplifiers were interfaced with a Macintosh IIci computer using the Superscope program (GW Instruments, Inc; Somerville, Mass). This program were used to filter and rectify the raw EMG signals. To obtain maximum EMG levels of the selected muscles for normalization, three maximum effort isometric contractions were performed before the experimental trials.

3. Anthropometric measurements

Trochanteric leg length, height, and weight were measured and recorded for each subject's right leg. Trochanteric height was the distance between the trochanteric and the floor when the subject stood erect, and 100% of trochanteric leg length was used to calculate the saddle heights used in this study.

4. Videotaping

Two S-VHS video cameras (Panasonic Digital 5000) were used to record cycling movements of each subject. The cameras were positioned ten meters from the subjects and were placed at a 90 degrees angle to each other. To synchronize the EMG and video, a synchronization unit was activated during the time the EMG was sampled. The synchronization was accomplished by using a digital trigger connected to both systems to initiate data collection.

5. Trial

There was an informational meeting for the subjects prior to the study. The subjects were then informed of the study's procedures and learned to perform the required exercises. Test protocol required each rider to pedal at a pedalling frequency of 80 rev/min. A speedometer mounted on the handlebars provided subjects with feedback on the pedalling rate. Because tire pressure affects rolling friction and thus the work needed to turn the pedals. the tires were kept at a constant pressure of 80 PSIG during the experiment. Prior to testing, the bicycle was aligned according to 100% of trochanteric leg length of each subject. The subject then rode a conventional racing bicycle with toe-clips mounted on the Wind Trainer (system of Schwinn II magnetic roller) at three different pedal shaft widths (normal, two inches, and four inches). Three different pedal shaft widths were randomly ordered and tested to prevent a treatment effect. All the subjects were allowed to warm up and practice for five minutes at the bicycle adjustment described above. Each three minute data collection period yielded two maximum isometric contractions: the knee flexed approximately 45 degrees and was extended approximately 45 degrees. Also three separate data of five seconds each were collected.

Upon completion of each of the trials, the subject dismounted from the bicycle and was givens a 5-minute rest period. The crank width was changed and, upon completion of the rest period, the subject remounted the bicycle. The final two trials were completed in the same manner as was described previously, except for the variation of pedal shaft length.

6. Data Analysis

The raw EMG signals were band pass filtered at a cutoff frequency range of 10-350 Hz and full-wave rectified. The area under the curve (IEMG) for each condition were determined. The average and peak EMG signals were further normalized to the maximum EMG levels observed during the isometric trials. The EMG activity level for each of 3 complete pedal revolutions was measured and analyzed for each muscle. The average value of these samples was used in the further analyses.

7. Statistical Analysis

For each trial, the average and peak normalized EMG levels of each muscle over three different pedal shaft widths were determined. A one-way analysis of variance with repeated measured was conducted to determined whether there were significant differences among three different pedal shaft widths. When a significant difference was found, post hoc analyses were performed using the Newman Keuls post hoc analysis. A confidence level of $p<.05$ was used to determine statistical significance.

Ⅲ. Results

1. Integrated EMG Activity

The activity of the muscles was recorded in terms of an integrated EMG. Comparison of each muscle's IEMG values while cycling under each pedal shaft width is shown in Table 1. Only the BF and VM data indicated a significant difference among three pedal shaft widths. Then Newman Keuls post hoc analyses indicated significant smaller IEMG value of the BF in the two inch pedal shaft when compared to the other pedal shafts. The post hoc analyses also revealed significant differences in the VM between the four inch pedal shaft and the other pedal shafts.

During the pedalling of the two inch pedal shaft width, all muscles decreased in the IEMG values compared to using the normal pedal shaft width. However, the comparison between the two inch and the four inch shaft width indicated that cycling with the four inch pedal shaft caused three muscle (BF, VL, and RF) to increase in activity by 16% when compared to the normal pedal shaft.

Table 1. Mean and standard deviations of average EMG activity values (%MVC)

	Rectus Femoris	Vastus Lateralis	Vastus Medialis	Biceps Femoris
Normal	54.0 (6.4)	19.6 (4.5)	25.0 (8.1)*	16.5 (4.6)δ
Two inches	20.2 (4.9)	18.9 (4.5)	23.9 (10.4)§	12.3 (1.5)
Four inches	21.9 (7.7)	20.2 (4.4)	20.3 (6.0)	14.3 (3.4)¤

Note. Standard deviations in parentheses.
* Significantly different ($p<.05$) than four inches
§Significantly different ($p<.05$) than four inches
δSignificantly different ($p<.05$) than two inches
¤ Significantly different ($p<.05$) than two inches

2. Maximum EMG Activity

The peak muscular activity values for the RF, VL, VM, and BF are presented in Table 2. A one-way analysis of variance with repeated measured for all four muscles studied failed to demonstrate any significant differences in %MVC activity. However, the %MVC values indicated that the two inch pedal shaft width for the RF, VL, and BF was 78.9%, 46.8%, and 66.1% of MVC respectively, less than both the normal and the four inches pedal shaft width.

Mean BF peak activity values ranged from 66.1% MVC for the two inches pedal width to 71.3% of MVC for the four inches pedal shaft width. The four inches pedal shaft width was greater than other pedal shaft widths, and the normal pedal shaft width was greater than the two inches pedal shaft width. Average VL peak activity values ranged from 46.8% of MVC for the two inches pedal shaft width to 58.9% of MVC for the four inches width. The greatest %MVC value of RF was recorded for the four inches pedal shaft width. Although there were no significant differences among three pedal shaft widths for the VM, Table 2 revealed that an increased pedal shaft width caused a decrease in the VM muscular activity. Mean VM activity values ranged from 84.7% of MVC for the four inches pedal shaft width to 90.4% of MVC for the normal pedal shaft width.

Table 2. Mean and standard deviations of maximum EMG activity values (%MVC)

	Rectus Femoris	Vastus Lateralis	Vastus Medialis	Biceps Femoris
Normal	86.4 (13.5)	55.7 (15.0)	90.4 (16.5)	67.4 (15.0)
Two inches	78.9 (12.1)	46.8 (12.7)	86.9 (17.0)	66.1 (14.1)
Four inches	91.2 (14.9)	58.9 (16.6)	84.7 (13.8)	71.3 (14.6)

Ⅳ. Discussion

Table 1 showed that an increase in pedal shaft width significantly decreased the integrated muscle activity in the VM while two inches pedal shaft width significantly decreased the integrated muscle activity in the BF. The RF and VL muscles investigated were not significantly influenced by change of the pedal shaft width. Although the difference in the IEMG values of the VM and BF muscles may have been caused by altered muscle and joint mechanics as a result of the pedal shaft width, other factors may also have contributed to the observed differences. The results imply that difference in muscular activity may be related to individual rider pedalling technique or to the adjustment of the subject's pedalling technique to the pedal shaft width.

The quadriceps are considered a knee extensor muscle, whereas the BF is thought of as a knee flexor. Therefore, the quadriceps and BF muscles appear to have opposite functions at the knee joint. However, contrary to anatomical results, the results in this study showed that overlap of the quadriceps and BF muscles was observed experimentally during cycling. The two EMG studies by Gregor et al. (1982, 1985) and other studies by Desipres (1974), Suzuki et al. (1982), and Ryan et al. (1988, 1989) support these results. However, there are several studies (Houtz and Fischer, 1959; Ericson et al., 1985; Jorge and Hull, 1986) that did not report any overlap between the quadriceps and BF activity during cycling. However, all EMG studies are consistent in showing that the EMG activity in the BF occurs well after that of the quadriceps EMG activity.

The average %MVC values for the RF, VL, VM, and BF reported in the present study ranged from 46.9 and 91.2 %MVC. Gregor et al. (1982) illustrated the average activity patterns of eight leg muscles while cycling. They reported that six of the eight muscles were very active (greater than 50 %MVC) during the first half of propulsion. The values presented in Gregor's study were similar to data found in the present study. However, Ericson reported lower %MVC values (less than 50%

MVC) than obtained in both the present study (Table 2) and Gregor's study. Several explanations may account for these reported differences. The subjects in the present study used toe-clips that allowed more muscle groups to participate in moving the pedals. Because cleated shoes and toe-clip permit the application of productive pedal forces, shoe-pedal interfaces may affect muscle activation patters. Ericson (1986) and Ericson et al., (1986) investigated the change in lower-limb muscular activity when using toe-clips. He found that toe-clips significantly increased the muscular activity in the RF, BF, and tibialis anterior muscles.

The considerable differences in %EMG values between the present study and Gregor's study are probably due to the differences in rate of pedalling. Ericson et al. (1985) and Goto et al. (1976) found the EMG values was affected by rate of pedalling.

Pedalling rate used in the present study was greater than the corresponding value for Gregor's study. It seems reasonable to assume that an increased pedalling rate may lead to an increased the muscular activity.

The final explanation is related to the degree of experience in changing a different pedal shaft width, and may have altered their muscular patterns. When comparisons were made among three pedal shaft widths in which both magnitudes and timing were shown, variations in activation patterns were observed.

Based on the present biomehcanical analysis, cycling with appropriate adjustments of the pedal shaft width may cause alteration in muscular patterns and lead to alteration in joint stresses. A controlled stress can be applied to the ligament to strengthen these muscles gradually over the period of the rehabilitation.

The typical woman has shorter arms and torso, and narrower shoulders but a wider pelvis than a man. The female cyclists who by virtue of pelvic width may have a less efficient pedalling force, or an imbalance of applied muscular force. Because of these reasons, her bike should be designed differently. Currently, there are a few bicycle alterations that are available for the women cyclists. Modification in the bicycle system specific for women can be suggested with the result of the present study. Because it was found that different pedal shaft widths had an effect on changes in EMG activity, it seems reasonable to suggest that different pedal shaft widths should be provided for different cyclists.

Although the present study has demonstrated muscle activity changes associated with different pedal shaft widths, additional research is certainly warranted to verify the exact differences in EMG activity. This additional research should include a large sample size with male subjects as well as smaller amounts of change to pedal shaft widths. In addition, if we measure exact crank position as well as the relative pedal position with respect to the crank, any additional study should use a potentiometer.

V. Conclusion

1. An increase in pedal shaft width significantly decreased the integrated muscle activity in the VM while two inches pedal shaft width significantly decreased the integrated muscle activity in the BF.
2. It was found that different pedal shaft widths had an effect on changes in EMG activity, it seems reasonable to suggest that different pedal shaft widths should be provided for different cyclists.

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