RESEARCH ARTICLE

Open Access

The effect of bicycle seat-tube angle on muscle activation of lower extremity

Chia-Hsiang Chen[1]✉, Ying-Hao Huang[1], Tzyy-Yuang Shiang[2]

Abstract

To investigate lower extremity muscle activation at various bicycle seat-tube angles. Twenty healthy participants (10 males and 10 females) with right dominant leg were recruited for this study. The study recorded the rectus femoris, hamstring, tibialis anterior, and gastrocnemius medialis in five different seat-tube angles conditions at 59, 69, 79, 89, 99 degrees. One-way analysis of variance with repeated measures was used to analyze all the data. The level of significance was set at α = .05. A steeper bicycle seat-tube angle reduced the muscle activation of the rectus femoris, hamstring and gastrocnemius during the downstroke phase. However, when the seat-tube angle was increased to 99°, the muscle activation of the rectus femoris and hamstring increased. In addition, the activation of tibialis anterior muscle decreased as the seat-tube angle increased. Lower extremity function can be changed by adjusting the seat-tube angle. At seat-tube angles of less than 90°, a steeper seat-tube angle can enhance pedaling efficiency. For lower extremity, a seat-tube angle greater than 90° can be used for rehabilitation and training.

Keywords: EMG, saddle positions, cycling, bike fitting

✉ **Contact email:** *doof75125@hotmail.com* (CH Chen)

[1] *Department of Physical Education, National Taiwan Normal University, Taiwan, Province of China*

[2] *Department of Athletic Performance National Taiwan Normal University, Taiwan, Province of China*

Received: 28 September 2013. Accepted: 10 April 2014.

Introduction

Increasing the bicycle seat-tube angle (STA) can decrease the torso angle, reduce wind resistance, and enhance aerodynamic effects (Hausswirth et al. 2001), thereby enhancing performance during racing competition. The bicycle seat tube angle is defined as the angle between seat tube and horizontal axis at bottom bracket. Previous study has shown that different lower extremity joint angle can change the lower-limbs' muscle activation and kinematics (Chen et al. 2013b). In addition, increased height of saddle position can alter a rider's posture of knee angle resulting in muscle strength and contraction velocity change (Browning et al. 1992; Reiser et al. 2002; Savelberg et al. 2003). Therefore, STA is extremely crucial to affect anatomical advantage and performance of bicycle.

Currently, the road-bike STA is between 72° and 76° (Hunter et al. 2003; Ricard et al. 2006) and the STA for triathlon is between 78° and 82° (Price and Donne 1997). Triathletes believe that a steeper STA (~80∘) can increase power output, making it more efficient, and a comfortable posture during cycling. (Hunter et al. 2003; Price and Donne 1997).

Previous research has indicated that at STAs of 76°, 83°, and 90°, oxygen consumption and average heart rate were reduced compared with an STA of 69° (Heil et al. 1995). In addition, an STA of 74° yields a higher power output and less oxygen consumption than an STA of 68° (Price and Donne 1997). An STA between 72° and 76° yields optimal cycling performance (Hunter et al. 2003). When the STA increased to 81°, muscle fatigue was delayed (Garside and Doran 2000). Moreover, when STA increased to 82°, power output increased and muscle activation was reduced (Ricard et al. 2006). Contradictory to the study above, researches showed that a change in STA (73°–81°) exerts no effect on heart rate variability (Jackson et al. 2008), the range of motion of lower extremity joints, energy metabolism, or muscle energy consumption (Bisi et al. 2012).

The discrepancies in cycling literatures may be due to different bicycle frames used in those studies. In most existing studies, position (seat and handlebar) was adjusted based on the existing bicycle frame geometry (Hunter et al. 2003; Ricard et al. 2006), and the adjustable STA was typically limited by the original bicycle design (Bisi et al. 2012). In addition, adjusting the STA altered the distance between the bicycle handlebar and saddle, affecting the torso angle and thereby possibly resulting in inconsistent experiment results. Therefore, a bicycle frame that allowed the STA to be altered in accordance with the distance between the bicycle handlebar and saddle may provide more insightful information regarding the relationship between bicycle and lower extremity geometries. Furthermore, most studies investigating bicycle saddle adjustment focused on elite cyclists (Bini et al. 2012; Bisi et al. 2012). However, the majority of bikers are for the purpose of regular exercise and leisure activity. Therefore, the purpose of this study was to investigate the lower extremity muscle activation at various STAs. On the hypothesis was that a steeper bicycle STA will reduce lower extremity muscle activation during the downstroke and upstroke phases on recreational bicycle riders.

Materials and methods

This study was approved by the Institutional Review Board of the local Medical University Hospital, and informed written consent was obtained from all participants prior to testing. Twenty healthy participants (10 males and 10 females) with right dominant leg were recruited for this study and, the body composition of the participants were shown in Table 1. The inclusion criteria for participating in this study was 100 min/week minimum cycling. None of the participants had received serious injuries to their lower extremities causing them to seek medical help in the year before the study was conducted.

To investigate muscle activity in the lower extremities, electromyography signals were obtained from the muscle groups on dominant sides, including the rectus femoris (RF), hamstring (HAM), tibialis anterior (TA), and gastrocnemius medialis (GAS). The electrode placements are described as follows: (1) For the RF, the electrode was placed at the midpoint between the anterior superior iliac spine (ASIS) and the superior aspect of the patella; (2) For the HAM, the electrode was placed at the midpoint between the distal ischial tuberosity and the popliteal fossa; (3) For the TA, the electrode was placed in the upper-third of the muscle, which extends from the tibial head to the medial malleolus; (4) For the GAS, the electrode was placed at the one hand breadth below the popliteal crease on the mass of the calf. Active electrodes (TSD150 series, Biopac Systems Inc., Goleta, CA, USA) were used to record muscle activation signals. The reference electrode was placed on the lateral malleolus of the right ankle. The electrodes (5 mm in diameter) were positioned with an interelectrode distance of 20 mm. The skin where the electrodes were placed was shaved and cleaned with alcohol. And the skin preparation before application of surface electrodes ensured that the interelectrode resistance was below 5 Kohms. The EMG signal sampling rate was set at 1000 Hz (pre-amplifier: common mode rejection ratio = 95 dB; impedance = 100 M ohms; gain = 350). All EMG signals were recorded using an acquisition system (Biopac MP150, Biopac Systems Inc., Goleta, CA, USA) into a personal computer. Before the start of the cycling trials, the electrodes were adhered to participants' muscles to record maximal voluntary isometric muscle contraction signals, which were used as the normalized standard signals. The MVC tests were completed in accordance with the manual muscle testing by Perotto and Delagi (2005) method.

In order to thoroughly understand the effect of bicycle STA on lower extremity muscle activation. Wider range of different STA conditions at 59, 69, 79, 89, 99 degrees were collected as shown in Figure 1. The central position was defined at the trunk flexion in 45∘relation to a non-sloping top tube (Silberman et al. 2005) and seat position was set at 95% of trochanter length (Sanderson and Amoroso 2009) in position of STA at 79 degrees. The order of conditions was based on a counter balance design to prevent order bias. Each participant performed each condition within 2 min, with a 2-min break between trials to prevent muscle fatigue. Metronomes were used to control the pedaling cadence at 90 rpm, and no extra resistance was applied on the ergometer. When the participants' riding patterns became stable and consistent (typically 4–5 cycles after the start of the trial), we marked the signals and recorded the EMG in the muscles of lower extremities for 1 min. One minutes EMG truncated starting at fifth cycling cycles was analyzed.

This study defined the period of leg activity according to the crank angle. The crank angle at 0˚ was equal to top dead center, 0–180˚ was defined as the downstroke period, and 180–360˚ was defined as the upstroke period (So et al. 2005).

The LabVIEW 8.5 (National Instruments, USA) software was applied to analyze the EMG signals. A fourth-order Butterworth filter was used to filter and smooth the EMG raw data. The EMG signals were filtered using a band pass filter (10-500 Hz), and then processed using full-wave rectification and were smoothed at a low frequency of 6 Hz to obtain a linear envelope graph. The EMG data were normalized using the maximal voluntary contraction (MVC) (Robertson 2004).

An one-way analysis of variance (ANOVA) with repeated measures was used to analyze all the data. Greenhouse-Geisser correction was employed when data violated the sphericity assumption. Post hoc were performed using Bonferroni when main effects were significant after ANOVA. The level of significance was set at α = .05. Partial eta squared (partial η^2) and observed power values were calculated to complete the analysis. Partial η^2 was used to calculate effect sizes, with outputs of 0.5 or greater considered a large effect size, 0.1-0.5 a moderate effect size and less than 0.1 a small effect size (Field 2009).

Table 3. The body composition of the participants

	Males (n=10)	Females (n=10)
Age (year)	24.7 ± 1.9 (rang: 22.8~27.8)	24.0 ± 2.0 (rang: 20.9~27.9)
Weight (Kg)	69.2 ± 6.2 (rang: 58.7~80.0)	55.1 ± 4.2 (rang: 49.2~59.3)
Dominate leg length (cm)	89.3 ± 2.5 (rang: 85.5~94.0)	82.4 ± 3.2 (rang: 78.0~87.5)

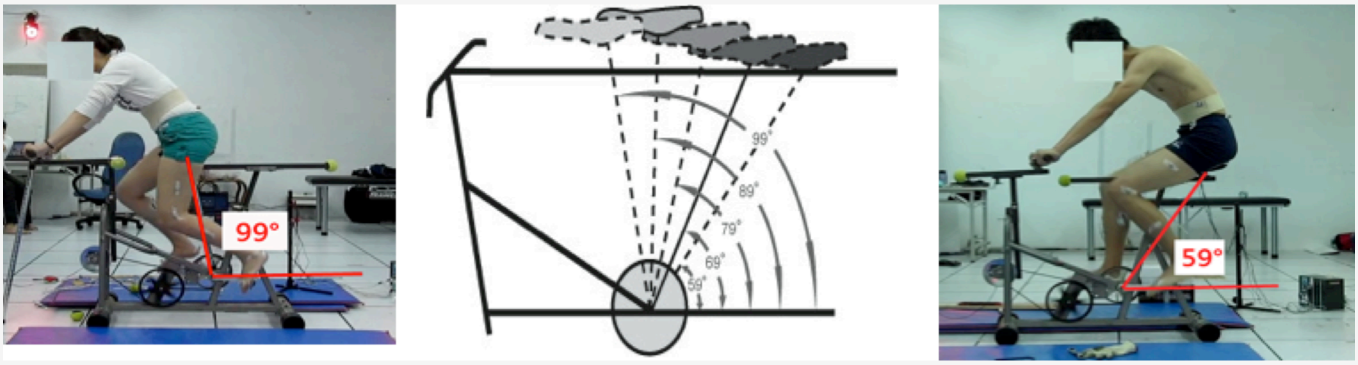

Figure 1. Five riding seat positions of different seat-tube angle conditions.

Results

The one-way ANOVA revealed that significant difference was found for the RF ($F_{(2.471,\ 46.941)}$=7.908, p=0.001, partial η^2 = .294), HAM ($F_{(1.750,\ 33.257)}$=8.633, p=0.001, partial η^2 = .312), TA ($F_{(2.070,\ 39.326)}$=29.298, p=0.000, partial η^2 = .607,) and GAS ($F_{(2.618,\ 49.747)}$=68.632, p=0.000 partial η^2 = .783,) at the downstroke period. Post hoc comparisons showed that the EMG of seat position at 99° STA were significantly higher than 69°, 79°, 89° STAs, as well as the EMG of seat position at 59° STA were significantly higher than 89° STA on RF, HAM, TA and GAS. Furthermore, the muscle activation of HAM showed no significant difference between 99° STA and 69° STA. On the other hand, the results showed that the EMG of seat position at 59° STA were significantly higher than 69°, 79° STAs on TA and GAS. Mean ± SD of the muscle activation at different STAs are shown in Table 2.

The one-way ANOVA revealed that significant difference were found among the RF ($F_{(2.604,\ 49.481)}$=6.290, p=0.002, partial η^2 = .249), HAM ($F_{(1.553,\ 29.129)}$=39.724, p=0.000, partial η^2 = .676), and GAS ($F_{(2.310,\ 43.896)}$=3.738, p=0.026 partial η^2 = .696,) at the upstroke period. Post hoc comparisons showed that the EMG of seat position at 59° STA were significantly lower than 89° STA on RF. The EMG of seat position at 99° STA were significantly higher than 59°, 69°, 79° and 89° STA on HAM. The power values as a range (0.931~0.999) for all variables since they are all relatively high.

Discussion

The results indicated that a steeper bicycle STA reduced the muscle activation of the gastrocnemius, rectus femoris, and biceps femoris during the downstroke phase, except for 99°. In addition, the activation of tibialis anterior muscle decreased as the STA increased in all conditions.

Previous studies showed that the STA was increased from 73.5° to 78°, the muscle activation of the biceps femoris and gastrocnemius decreased (Bisi et al. 2012; Ricard et al. 2006). On the other hand, a similar change in STA (73° to 81°) exerted no effect on energy consumption on triathletes (Bisi et al. 2012; Jackson et al. 2008). However, this study investigated recreational cyclist, and found that a change in the bicycle STA altered lower extremity muscle activity. Previous research demonstrated that torso anteversion increased and hip range of motion altered with increased STA. (Hausswirth et al. 2001; Hunter et al. 2003; Savelberg et al. 2003). Studies also indicated that moving the saddle position forward altered the range of motion of the entire lower extremity geometry (Bini et al. 2012; Chen et al. 2013a) and affected muscle activation and length, as well as muscle contraction velocity (Hug and Dorel 2009; Reiser et al. 2002; Savelberg et al. 2003), resulting in better power output during cycling (Bini et al. 2012; Reiser et al. 2002; Savelberg et al. 2003). According to our results, for recreational cyclists under the same resistance load, increasing the STA without

Table 2. The muscle activation (% MVC) at different STAs (59, 69, 79, 89 and 99 degrees) on lower extremity muscles (RF, HAM, TA and GAS) during the downstroke and upstroke phases. All values expressed as Mean±SD.

	phase	99°			89°			79°			69°			59°		
RF	Downstroke#	8.51	±	2.28	6.63	±	0.83a	7.08	±	1.80a	7.27	±	1.62a	7.97	±	1.19b
	Upstroke#	7.59	±	3.11	7.17	±	2.31	7.67	±	2.88	8.64	±	4.22	8.67	±	3.01b
HAM	Downstroke#	8.03	±	1.76	6.61	±	0.97a	6.54	±	0.78a	7.01	±	0.92c	7.27	±	0.92b,c
	Upstroke#	10.44	±	2.66	7.28	±	1.85a	6.64	±	0.96 a	6.34	±	0.85a	6.32	±	0.83a
TA	Downstroke#	10.81	±	2.91	8.80	±	2.27a	7.23	±	1.37a,b	7.13	±	1.83a,b	6.63	±	1.23a,b
	Upstroke	11.32	±	4.68	10.49	±	3.73	9.34	±	3.45	9.84	±	4.76	9.45	±	3.70
GAS	Downstroke#	12.95	±	1.94	16.53	±	2.27a	18.61	±	2.14a,b	20.50	±	3.26a,b	24.05	±	3.62a,b,c,d
	Upstroke#	10.29	±	2.83	10.59	±	3.08	11.71	±	3.28	11.63	±	3.47	12.21	±	3.95

#: Indicate significant difference among five riding seat positions of different STAs conditions (p < .05).
a: Indicate that 99 STAs values were significantly higher (or lower) than other STAs values (p < .05).
b: Indicate that 89 STAs values were significantly higher (or lower) than other STAs values (p < .05).
c: Indicate that 79 STAs values were significantly higher (or lower) than other STAs values (p < .05).
d: Indicate that 69 STAs values were significantly higher (or lower) than other STAs values (p < .05).

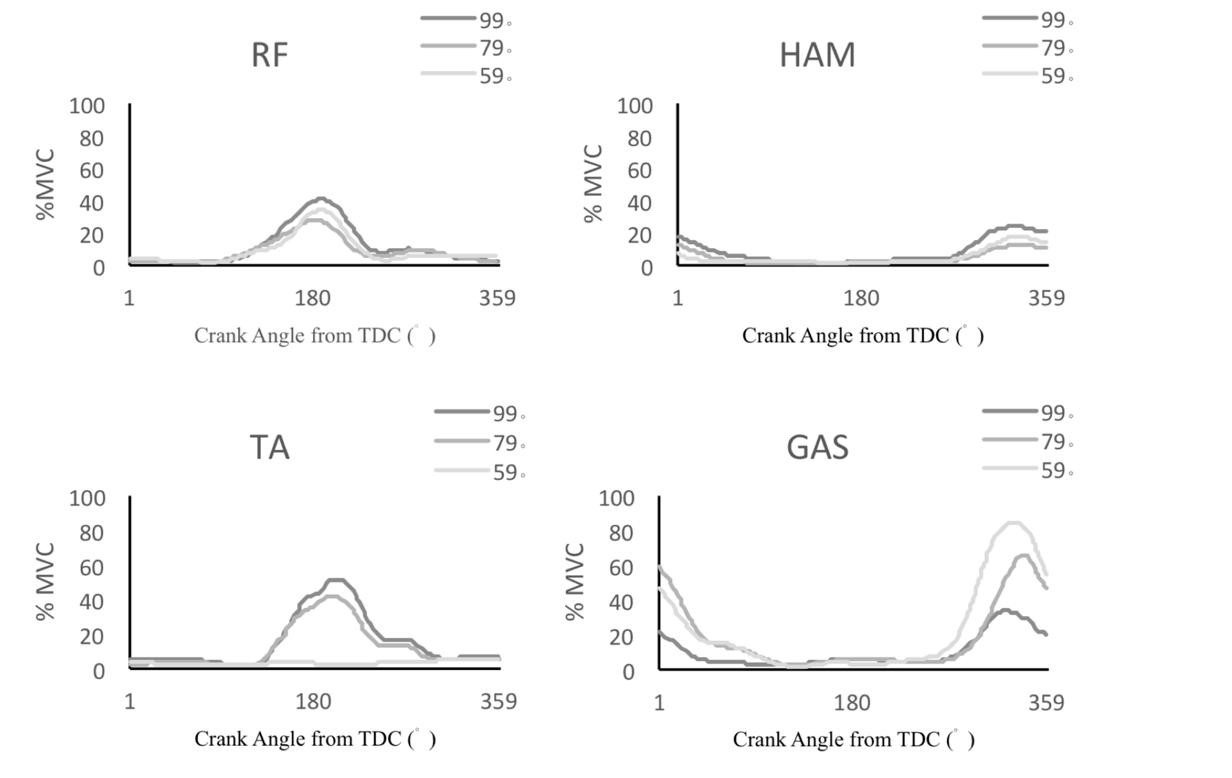

Figure 2. RMS EMG envelope for 4 lower extremity muscles obtained from different STAs of 59, 79 and 99 degrees. RF, rectus femoris; HAM, hamstring; TA, tibialis anterior and GAS, gastrocnemius medialis.

exceeding 90° reduced muscle activation during bicycling. Previous research showed that the same power producing with a reduced demand on muscle activation during the cycling indicating better pedaling efficiency (Blake et al. 2012) .

In addition to performance, cycling exercise has also been used for rehabilitation for knee injuries. (Fleming et al. 1998; Kutzner et al. 2012). However, the anatomical geometry that can provide enhanced muscle training have not been identified. Previous research showed that a relatively backward saddle position, pedaling required a greater knee flexion angle (Bini et al. 2012) and required ankle joints to produce greater planar flexion (Price and Donne 1997; Rottenbacher et al. 2009). Intriguingly, this study found that at a small STA (59°) can increase the electromyographic activation of the biceps femoris and gastrocnemius. Noticeably, this study found that the muscle activation of the rectus femoris and biceps femoris decreased as the STA increased from 59° to 89°, except when STA increased to 99°. At an STA of 99°, the body moved forward and the riding posture was similar to a standing riding position. A standing riding position allows the rider to use their body weight to increase pedaling strength and increase lower extremity muscle activation (Duc et al. 2008). Therefore, at an STA of 99°, cycling induced greater thigh muscle activation, in particular in the biceps femoris, muscle activation occurred during both downstroke and upstroke phases.

The support of bicycle saddle reduced the body weight load on the joint ligaments of lower extremity (Fleming et al. 1998). According to our results, at a constant load, a 99° STA can increase thigh muscle activation during pedaling. A riding position with an STA of 99° is a suitable choice for patients who require lower extremity rehabilitation. In addition, moving the bicycle saddle forward can reduce the shear forces across the knee joints (Bini et al. 2013). Thus, this study found that a bicycle frame with a steeper STA might be used for knee rehabilitation after knee operation.

Practical applications

This study found that various bicycle STAs affected lower extremity muscle activation, particularly for general bicycle enthusiasts. Lower extremity function can be changed by adjusting the STA. A steeper STA can reduce the load on lower extremity muscles which might enhance pedaling efficiency at SATs between from 59° to 89°. For lower extremity training, a STA greater than 90° may be useful for cycling to increase the load on lower extremity muscles and achieve effective muscle training. In addition, a bicycle frame with a steeper STA would be beneficial for knee rehabilitation after knee operation.

Acknowledgment

This study was funded by ‘‘Aim for the Top University Project’’ of the National Taiwan Normal University and the Ministry of Education, Taiwan, R.O.C.

References

1. Bini RR, Hume PA, Lanferdini FJ, Vaz MA (2012) Effects of body positions on the saddle on pedalling

technique for cyclists and triathletes. European Journal of Sport Science: 1-8

2. Bini RR, Hume PA, Lanferdini FJ, Vaz MA (2013) Effects of moving forward or backward on the saddle on knee joint forces during cycling. Phys Ther Sport 14: 23-27
3. Bisi MC, Ceccarelli M, Riva F, Stagni R (2012) Biomechanical and metabolic responses to seat-tube angle variation during cycling in tri-athletes. J Electromyogr Kinesiol 22: 845-851
4. Blake OM, Champoux Y, Wakeling JM (2012) Muscle coordination patterns for efficient cycling. Med Sci Sports Exerc 44: 926-938
5. Browning R, Gregor R, Broker J (1992) Lower Extremity Kinetics in Elite Athletes in Aerodynamic Cycling Positions. Med Sci Sports Exerc 24: S186
6. Chen C-H, Chang P-L, Shiang T-Y (2013a) The efficiency of lower extrmity movement in different seat positions during cycling. Paper presented at the Proceedings of the XXIV Congress of the International Society of Biomechanics: 4-9 August 2013; Natal, Brazil
7. Chen Y, Wu K-Y, Tsai Y-J, Yang W-T, Chang J-H (2013b) Kinematics for 3 different distances of crouch starts in sprints Physical Education Journal 46: 23-30
8. Duc S, Bertucci W, Pernin J, Grappe F (2008) Muscular activity during uphill cycling: effect of slope, posture, hand grip position and constrained bicycle lateral sways. Journal of Electromyography and Kinesiologyv 18: 116-127
9. Field A (2009) Discovering Statistics Using SPSS. Sage publications, London
10. Fleming BC, Beynnon BD, Renstrom PA, Peura GD, Nichols CE, Johnson RJ (1998) The strain behavior of the anterior cruciate ligament during bicycling. An in vivo study. Am J Sports Med 26: 109-118
11. Garside I, Doran DA (2000) Effects of bicycle frame ergonomics on triathlon 10-km running performance. J Sports Sci 18: 825-833
12. Hausswirth C, Vallier J-M, Lehenaff D, Brisswalter J, Smith D, Millet G, Dreano P (2001) Effect of two drafting modalities in cycling on running performance. Med Sci Sports Exerc 33: 485-492
13. Heil DP, Wilcox AR, Quinn CM (1995) Cardiorespiratory responses to seat-tube angle variation during steady-state cycling. Med Sci Sports Exerc 27: 730-735
14. Hug F, Dorel S (2009) Electromyographic analysis of pedaling: a review. J Electromyogr Kinesiol 19: 182-198
15. Hunter AM, Gibson ASC, Lambert MI, Nobbs L, Noakes TD (2003) Effects of supramaximal exercise on the electromyographic signal. Br J Sports Med 37: 296-299
16. Jackson K, Mulcare J, Duncan R (2008) The effects of bicycle seat-tube angle on the metabolic cost of the cycle-run transition in triathletes. J Exerc Physiol Online 11
17. Kutzner I, Heinlein B, Graichen F, Rohlmann A, Halder AM, Beier A, Bergmann G (2012) Loading of the knee joint during ergometer cycling: Telemetric in vivo data. J Orthop Sports Phys Ther 42: 1032-1038
18. Perotto AO, Delagi EF (2005) Anatomical guide for the electromyographer: The limbs and trunk. Charles C Thomas Publisher
19. Price D, Donne B (1997) Effect of variation in seat tube angle at different seat heights on submaximal cycling performance in man. J Sports Sci 15: 395-402
20. Reiser R, Peterson M, Broker J (2002) Influence of hip orientation on Wingate power output and cycling technique. The Journal of Strength & Conditioning Research 16: 556-560
21. Ricard MD, Hills-Meyer P, Miller MG, Michael TJ (2006) The effects of bicycle frame geometry on muscle activation and power during a Wingate anaerobic test. Journal of Sports Science and Medicine 5: 25-32
22. Robertson DGE (2004) Research Methods in Biomechanics. Human Kinetics Publishers
23. Rottenbacher C, Zaccaria D, Gualea MR, Mimmi G, Bonandrini G, Buzzi E (2009) A study on the biomechanical efficiency of different cycling positions. Paper presented at the XIX Congress AIMETA Italian Association for Theoretical and Applied Mechanics: 14-17 September 2009; Ancona
24. Sanderson DJ, Amoroso AT (2009) The influence of seat height on the mechanical function of the triceps surae muscles during steady-rate cycling. J Electromyogr Kinesiol 19: e465-e471
25. Savelberg HH, Van de Port IG, Willems PJ (2003) Body configuration in cycling affects muscle recruitment and movement pattern. J Appl Biomech 19
26. Silberman MR, Webner D, Collina S, Shiple BJ (2005) Road bicycle fit. Clin J Sport Med 15: 271-276
27. So RC, Ng JK-F, Ng GY (2005) Muscle recruitment pattern in cycling: a review. Phys Ther Sport 6: 89-96