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ORIGINAL

THE RELATIONSHIP BETWEEN PARAMETERS OF TENSIOMYOGRAPHY AND POTENTIAL PERFORMANCE INDICATORS IN PROFESSIONAL CYCLISTS

RELACIÓN ENTRE PARÁMETROS DE TENSIOMIOGRAFÍA Y POTENCIALES INDICADORES DEL RENDIMIENTO EN CICLISTAS PROFESIONALES

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ABSTRACT

The aim of this study was to establish the relationship of the time contraction (TC) and the radial muscle belly displacement (DM) of the vastus medialis, vastus lateralis, rectus femoris and biceps femoris muscles, assessed by tensiomyography, regarding potential sport performance indicators such as W_{max} and $VO2_{max}$ in professional road cyclists. A tensiomyography and a progressively incremental protocol until exhaustion point were reached in the laboratory conditions to 10 professional cyclists. The results show that there are correlations between performance indicators and the DM of biceps femoris and rectus femoris, and between the own indicators W_{max} and VO_{2max}. However, the TC has not correlated with any of them. In conclusion, the results suggest that DM of the biceps femoris and rectus femoris biarticular muscles could be related with these potential sport performance indicators of the professional cyclists.

KEY WORDS: Tensiomyography, professional road cyclist, maximal pedal power, maximal oxygen consumption.

RESUMEN

El objetivo de este trabajo fue el de establecer la relación del tiempo de contracción (TC) y el desplazamiento radial del vientre muscular (DM) de los músculos vastus medialis, vastus lateralis, rectus femoris y biceps femoris, evaluados mediante tensiomiografía, respecto a potenciales indicadores del rendimiento deportivo como son W_{max} y $VO_{2máx}$ en ciclistas profesionales de carretera. Se realizó una tensiomiografía y un test progresivo de esfuerzo máximo en laboratorio a 10 ciclistas profesionales. Los resultados muestran que existen correlaciones entre los potenciales indicadores del rendimiento y el DM de bíceps femoris y rectus femoris, así como entre los propios indicadores. No obstante, el TC no ha correlacionado con ninguno de ellos. En conclusión, los resultados sugieren que el DM de los músculos biarticulares bíceps femoris y rectus femoris podría estar relacionado con estos potenciales indicadores del rendimiento de los ciclistas profesionales.

PALABRAS CLAVE: Tensiomiografía, ciclista profesional, potencia máxima de pedaleo, consumo máximo de oxígeno.

INTRODUCTION

The maximum oxygen consumption (VO_{2max}) and maximum pedaling power (W_{max}) values have been consistently collected in the scientific literature (Mujika and Padilla, 2001). Both can be used as a physical performance predictor in cycling (Faria, Parker and Faria, 2005)

These potential performance predictors have been assessed in professional road cyclists according to their specialty (flat terrain, time trial, all terrain, uphill) (Mújika and Padilla, 2001) and as well as intensity indicators (%VO_{2max} and %W_{max}), that representing different types of cycling races such as the time trials, high mountain ascents or flat stages in tour races (Lucía**,** Hoyos and Chicharro, 2001).

Furthermore, tensiomyography (TMG) allows assess the muscles contractile properties in an isolated and involuntary way, through the detention of the maximum radial muscle belly displacement (DM) in an isometric contraction caused by an electrical stimulus.

This technique is based on assume that the displacement amount detected by the sensor is proportional to the muscular strength that can be generated by the assessed muscle (Valenčič and Djordjevič, 2001; Valenčič, Knez and Šimunič, 2001).

In fact the amplitude of the TMG response is directly related to the contractile strength carried out until approximately 68% of the maximum strength (Pišot et al., 2008).

The DM is the TMG parameter associated to the muscle tone (muscle stiffness) and to the changes in the muscle cross section, being able affected by the mechanical properties of the muscle tendon, since an increase in the values of this parameter has been attributed to a decrease in muscle and tendon tone (Pišot et al., 2008)

Another assessed parameter with TMG is the time contraction (TC), defined as the time between when the reaction time ends (10 %) and when the 90% of the maximum muscle deformation is produced, measured in milliseconds (Rodríguez-Matoso et al., 2010) This is significantly associated with the distribution of the different types of fibers determined by histochemical method through biopsy (Dahmane, Valenčič, Knez, and Erzen, 2001; Dahmane, Djordjevič, Šimunič, and Valenčič, 2005; Šimunič et al., 2011) The TC is considered as an important parameter to describe the skeletal muscles characteristics (Valenčič and Djordjevič, 2001).

The TMG has been used to differentiate the muscle characteristics in children and relate them to the performance in sprint tests (Pišot et al., 2004) However, the relationship between the muscle contractile properties, assessed through TMG, and the performance ability or the potential sport performance indicators has not been sufficiently dealt with in the scientific literature.

The aim of this study was to establish the relationship of the time contraction (TC) and the radial muscle belly displacement (DM) of the Vastus Medialis, Vastus Lateralis, Rectus Femoris and Bíceps Femoris muscles, assessed by TMG, regarding potential sport performance indicators such as W_{max} and VO_{2max} in professional road cyclists.

MATERIAL AND METHOD

This research has involved to 10 professional road cyclists, all volunteers, who gave their written consent after being informed, along with the technical staff and the team managers, of the entire assessment process and potential risks associated with the study. The research protocol followed the instructions specified in the Helsinki´s Declaration of biomedical research in humans (18^{th} Medical Assembly, 1964; revised in 1983 in Italy and in 1989 in Hong Kong), and it also followed the instructions about the preservation of humans´ rights and dignity in biological and medical applications (IR1999; B.O.E. 251, 1999) The study was approved by the local ethics committee.

Participants

The sample was composed of ten professional road cyclists (age 27,5 ± 5,5 years old; height 178,2 ± 7,8 cm; body mass 65,6 ± 5,4 kg) who had planned the “Vuelta a España” as main competition of the season. The team obtained a notable performance by winning the team classification. Despite the small sample number (n=10), it is important to note that this represents the 5,05% of the professional cyclists´ universe in that competition, also García-García, Hernández Mendo, Serrano-Gómez and Morales-Sánchez (2013) have suggested that the data structure obtained with these cyclists has shown, through a generalizability analysis, an adequate reliability and generalizability, achieving therewith an optimization of the measurement design too. For these authors, this type of analysis has a special relevant in studies where the sample of high-level athletes is always limited.

Assessment protocol

Each cyclist was assessed in the competition period, five weeks before the start of the “Vuelta a España”. The average distance covered in that moment in training and competitions was 20.600 ± 2.319 km. The measurements took place in the active rest day of each cyclist in their recovery microcycle. All cyclists were in a healthy state.

The TMG was carried out using always an electrical stimulus of 1 millisecond of duration. The stimulus initial intensity was 30mA and it was successively increasing in 10mA until reaching the maximum intensity of the electro stimulator TMG-S2 (EMF-FURLAN & Co. d.o.o., Ljubljana, Slovenia), situated in 110mA.

For each of the assessed cyclists, of the total of measurements obtained from each of their muscles, only which represented the highest DM (maximum radial muscle displacement) in each muscle was selected for a further analysis.

Between consecutives stimulus was allowed a rest period of 10 seconds to avoid possible effects of fatigue in the muscle, as indicated Krizaj Šimunič and Zagar (2008). In each measurement were observed two parameters: maximum radial muscle belly displacement (DM) expressed in millimeters and time contraction (TC) established as the time between the 10% and 90% of the maximum response of DM in the ascending zone of the curve, expressed in milliseconds. Both parameters had shown to have a high level of reliability and reproducibility in a short-term (Krizaj et al., 2008; Tous-Fajardo et al., 2010; Rodríguez-Matoso et al., 2010b).

The Vastus Medialis (VM), Vastus Lateralis (VL), Rectus Femoris (RF) and Biceps Femoris (BF) muscles of both legs were assessed in a static and relaxed way, with the cyclist in supine decubitus position to assess the knee extensor and in prone position to assess the knee flexor. The knee joint was determined using specific wedges which support the knee in 120º in supine position and 150º in prone position.

The radial muscle belly displacement was assessed using a digital transducer of displacement (GK 40, Panoptik d.o.o., Ljubljana, Slovenia) that was placed in a perpendicular way to the thickest part of the muscle belly. The placement of the sensor was determined individually following the indications of Delagi, Perotto, Lazzeti and Morrison (1975). The self-adhesive electrodes (5x5cm, 2mm/h. Conlin Medical Supply Co., Ltd, China) were placed symmetrically to 5 cm of the sensor. The measurement point was slightly corrected to obtain always the highest mechanical response (Pišot et al., 2008).

After a warm-up determined individually by each cyclist, they carried out a progressive test of maximum effort in laboratory, using a cycle ergometer of electromagnetic brake (Cardgirus bicycle SNT Medical. Spain) and following an incremental, continuous and progressive protocol until exhaustion. The expired gases were collected continuously throughout the test by a Jaeger Oxycon Pro® team (Erich Jaeger GmbH. Germany) which complies with ATS (American Thorazic Society) and ECCS (European Communities Chemistry Society) normatives.

Before each test, the gas analyser was calibrated using ambient air (20,9% O2 and 0,04% CO2) and by calibration bottle (16% O2, 5% CO2) The protocol consisted in being 3 minutes stopped on the cyclo ergometer, next pedaling during 3 minutes at an intensity of 20W, maintaining a constant pedaling frequency of 90 rev · min^{-1}, and subsequently increasing 5W each 15 seconds of pedaling (20W each minute) until exhaustion, or until the cyclist could not keep the pedaling cadence.

The obtained values have been defined in the Faria et al. (2005)´s study. The pedaling power was registered in watts through the Cardgirus Medical V. 4.3.0.10 software. W_{max} was obtained at the moment that the cyclist obtained the test highest value within the last completed charge. VO_{2max} that represents the maximum amount of oxygen used and the second ventilator threshold (VT_2) defined as the respiratory compensation point, which corresponds very roughly to the second lactate threshold (LT_2), were determined by the ventilator variables using the LabManager V4 software (Erich Jaeger GmbH. Germany).

The W_{max} and VO_{2max} values have been expressed in relative values to body mass (kg), because it has been demonstrated that when the elite cyclists are tested in laboratory conditions, the physiological values expressed in relative way to the anthropometric characteristics, predict more accurately the sport performance than absolute values (Padilla, Mújika, Cuesta, Polo and Chatard, 1996).

Statistical analysis

The Pearson´s bivariate correlation coefficient has been used to establish the relationship between TC, DM and the potential sport performance indicators W_{max} and VO_{2max}, and also among the own potential indicators (W_{max} and VO_{2max}) Due to the small sample size (n=10), complementary, Tau_b de Kendall and Rho de Spearman tests were implemented. The statistical significance level was set at *P<0,05* (*). The data were analyzed using SPSS (Statistical Package for the Social Sciences) for Windows 19 version.

RESULTS

The TC and DM results shown in the Table 1 are the average value between right and left side of each assessed muscle, since no significant differences were found between both sides.

	VM	VL	RF	BF
TC (ms)	40,6 ± 14,4	40,6 ± 10,2	45,9 ± 16,2	28,2 ± 5,2
DM (mm)	8,3 ± 1,5	5 ± 1,4	7,4 ± 2,8	5,2 ± 2,3
VO_{2max} (ml/kg/min)	72,1 ± 3,7 ml/kg/min^{-1}			
W_{max} (W/kg)	6,0 ± 0,4 W/kg			

Table 1. Descriptive values of TC (milisegundos), DM (milímetros), VO_{2max} and W_{max} relatives.

As shown in the table above, the RF is the muscle which presents a higher value of TC, being the BF which obtains a lower value. The VM is the muscle with a higher DM, while VL and BF have obtained the lowest DM.

The FC values achieved by cyclists in the maximal effort test were 176,7 ± 11 p/m in VT_2, and 188,3 ± 10,1 p/m in VO_{2max}. Regarding the maximum pedaling power, the absolute value was 407,0 ± 25,8 W and 6,0 ± 0,4 W/kg the relative value to the body mass. The watts moves in VT_2 have been 329,0 ± 39,0 W (4,9 ± 0,6 W/kg) and 390,0 ± 28,8 W (5,8 ± 0,4 W/kg) in VO_{2max}. Regarding the maximum oxygen consumption, the absolute value has been 4,9 ± 0,1 L/min and 72,1 ± 3,7 ml/kg/min^{-1} in relative value to the body mass. The oxygen consumption in VT_2 has been 62,6 ± 5,4 ml/kg/min^{-1}.

The results in the Table 2 show that the TC parameter has not significantly correlated with the potential performance indicators. However, the DM parameter presents correlations with the potential performance indicators. In particular, it is observed a positive correlation between VO_{2max} and DM of RF (r = 0,637; *P*<0,05), between VO_{2max} and DM of the BF (r = 0,680; *P*<0,05), and between W_{max} and DM of the BF (r = 0,652; *P*<0,05). It has not been found any significant correlation between the potential sport performance indicators and the VM and VL muscles.

	TIME CONTRACTION		RADIAL DISPLACEMENT	
	VO_{2max}	W/kg	VO_{2max}	W/kg
VM	-0,175	-0,097	-0,158	-0,059
VL	-0,119	-0,245	0,375	0,173
RF	-0,073	-0,032	**0,637***	0,264
BF	-0,012	0,095	**0,680***	**0,652***

Table 2 Pearson´s bivariate correlation coefficient between TC and DM of each assessed muscle and the potential performance indicators. *p<0,05 (*)*

It has been also found in the cyclists who comprise this sample, a positive correlation between the two potential indicators of the W_{max} and $VO_{2máx}$ performance (r = 0,691, P<0,05).

DISCUSSION

The volume of kilometers covered by the participants of this sample (to 5 weeks of the “Vuelta a España”) is in line with the described by The Mújika and Padilla (2001) and by Lucía et al. (2001).

The maximum pedaling power (W_{max}) is a performance indicator whose power / weight ratio, for that a cyclist was considered of elite, must be higher than 5,5 W/kg (Faria et al., 2005). The W_{max} value of the cyclists who comprise this sample, fulfills with this requirement (6,0 ± 0,4 W/kg), although it is shown slightly lower than the values reported by Padilla, Mújika, Cuesta and Goiriena (1999) with a value of 6,3 ± 0,3 W/kg, by Mújika and Padilla (2001) in uphill specialists (6,5 ± 0,3 W/kg), in time trial specialists (6,4 ± 0,1 W/kg), and all terrain cyclists (6,4 ± 0,2 W/kg), and it is very similar to the flat terrain specialists (6,0 ± 0,3 W/kg), to the collected by Lee, Martin, Anson, Grundy and Hahn (2002) in professional road cyclists (5,8 ± 0,3 W/kg), and to the reported in their review by Lucía et al. (2001) of between 6,0 and 6,5 W/kg.

However, it is necessary to consider that the variation in W_{max} during the season has been reflected due to the training and the competition effects (Sassi, Impellizzeri, Morelli, Menaspá, and Rampinini, 2008). Also, the data generated in a progressive maximum effort test should be compared with caution because of the different protocols used in the test, since the highest maximum powers usually take place when the tests are of short duration (Lucia et al., 2001).

The VO_{2max} of the assessed cyclists has result to be similar to the noted in their review by Faria et al. (2005) with a value of 74,0 ml/kg/min^{-1}, to the collected by Lee et al. (2002) in professional road cyclists (73,0 ± 3,4 ml/kg/min^{-1}), to the reported by Lucía et al. (2001) between 70 and 80 ml/kg/min^{-1}, and to the specialists flat terrain, 74,4 ± 3,0 ml/kg/min^{-1}, assessed by Mújika and Padilla (2001). However, it is lower than to the reported by these last authors in the all terrain specialists 78,9 ± 1,9 ml/kg/min^{-1}), in time trial specialists (79,2 ± 1,1 ml/kg/min^{-1}), and in the uphill specialists (80,9 ± 3,9 ml/kg/min^{-1}).

The positive correlation between VO_{2max} and W_{max} of the studied cyclists is in line with the Lee et al. (2002)´s findings which showed the linear relationship between the pedaling power and the oxygen consumption in professional road cyclist and mountain bike cyclists, and also with the use of W_{max} as a predictor of the VO_{2max} that carry out Hawley and Noakes (1992) through the VO_{2max}= 0,01141 • W_{max} + 0,435 equation in trained cyclists.

The results show that the DM parameter of the BF correlates positively with both potential performance indicators. The BF is activated together with the knee extensor muscles to facilitate the action of pedaling between the 45º and the 180º (Hug and Dorel, 2009). This situation occurs in the leg rhythmic circular movements where the knee extensors muscle act together with their antagonists, in a concentric action, favoring the hip extension. This flexors activation, which appears at the end of this phase, will contribute when approaching to the 180º, is facilitated the necessary conditions for the rising of the pedal. Specifically, the BF long head, which has been assessed with TMG, is involved as in the hip extension as the knee flexion, given its condition of biarticular muscle.

The fact that it was the DM of the RF (knee extensor and hip flexor) the other muscle which had obtained a correlation with the VO_{2max}, suggests that the assigned task to these biarticular muscles in pedaling, collected in Hug and Dorel´s paper (2009): to contribute to the joint stability or to the energy transfer between joints at critical moments in the pedaling cycle, and in the control of the direction in the pedal of the produced power, could be fundamental to achieve good values of VO_{2max} and W_{max}, and thus to obtain an improvement of the sport performance.

These results suggest that the assessment and control of the DM, that is, the cyclists´ muscle tone and the cross section of the muscle belly and of the tendon, of the BF and of the RF, could be relevant to carry out the monitoring of their form status and their level of sport performance. However, the TC does not seem to be relevant in this case, although the relationship with the distribution of the different types of fibers determined by histochemical method, by biopsy (Dahmane et al., 2001; Dahmane et al., 2005; Šimunič et al., 2011) would show a priori the opposite, especially in the VL muscle, since the necessary efficacy in pedaling during the prolonged effort seems to be possible due to the higher percentage of Type I fibers which are found in the VL, that would be associated with a low submaximal oxygen consumption, which would increase considerably the efficiency (Faria et al., 2005). This efficacy would be the reflection of increasing the aerobic metabolism and the muscle power.

In this sense, it is not definitively explained the relationship between the TMG parameters and the potential performance indicators in professional cyclists. As

Lucía, Hoyos, Pardo and Chicharro (2000) suggest, there is an increase during the season of the recruitment of motor units in the active muscles, that is, it is produced neuromuscular adaptations, so it would be necessary to carry out a monitoring during all the season to determine how the relationship varies between the TMG parameters and the potential performance indicators. To understand these possible relationships is necessary to assume that it is been treating to relate the result of an involuntary, static, in isometric conditions and with a very short duration test, with other voluntary and dynamic, that require continuous isotonic contractions along a prolonged time. Therefore it seems necessary to continue monitoring the relationship between the TMG parameters and potential performance indicators in professional cyclists.

On the other hand, it would also be interesting to study other muscle groups which participate in the kinetic chain of pedaling, and use the power achieved separately on each leg to find more specific relations, since the pedaling power asymmetries between both legs may take place in the elite cyclists (Swart, Tucker, Lamberts, Albertus-Kajee, and Lambert, 2008) and seems that they are highly variable depending on the subjects and their characteristics (Smak, Neptune and Hull, 1999).

CONCLUSIONS

The results suggest that the DM may be a relevant parameter of the state of the cyclists´ muscles state, and also suggest the confirmation of the important role that the biarticular muscles BF and RF have in the professional cyclists´ pedaling, since, in the cyclists of our sample, this parameter in these muscles has shown to be related to potential indicators of the sport performance as are VO_{2max} and W_{max}.

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