A BIOMECHANICAL MODEL OF THE CERVICAL SPINE DURING CYCLING

Maicon Pasini, Cláudia Tarragô Candotti, Jefferson Fagundes Loss*, Mônica de Oliveira Melo*, Marcelo La Torre, Révisson Esteves da Silva, Ricardo Barreto Teixeira, Gustavo B. Delwing

University of Vale do Rio dos Sinos, São Leopoldo, Brazil
***Federal University of Rio Grande do Sul, Porto Alegre, Brazil**

With the objective of estimating the internal forces in the cervical spine during cycling, nine subjects pedaled in three postures. The image of the sagittal posture of the spine was recorded through filming and the muscle activity of the cervical extensors was registered. Reflexive markers were placed on anatomical points on the head and the cervical spine. One subject was submitted to radiological exam of the head and cervical spine in the sagittal plane with lead markers placed on the same anatomical points of reference. Muscular force was calculated using the inverse dynamics technique. The results demonstrate that muscular strength and the RMS value increase significantly ($p<0.05$) when the cervical spine is more extended and the head is pushed forward.

KEY WORDS: cervical spine, cycling, pain.

INTRODUCTION:

It has been reported that up to 70% of cyclists experience neck and back pain (Mellion, 1994; Salai et al., 1999). However, the etiology has not been totally clarified, the diagnosis often being non-specific chronic pain (Burnett et al., 2004).
Cyclists try to maximize their speed maintaining an aerodynamic posture, reducing the drag force (Kyle, 1994) and as they rode a bicycle for long periods, this could represent a cause of neck and back pain. It is possible to adequately research this process by estimating the forces acting on the spine during cycling, using techniques such as inverse dynamics and surface electromyography (EMG), since they have been successfully employed in studies of spinal injury and pain (Adams & Dolan, 2005).
Studies have suggested that the posture maintained by cyclists affects the physiological curvature of the spine (Vey Mestdagh, 1998; Silberman et al., 2005), the cervical area being the most affected. Injury and consequent pain could arise from extreme positions of the cervical and other areas of the spine (Vey Mestdagh, 1998).
Accordingly, the objective of this study was to develop a biomechanical model associated to the inverse dynamics technique that will be capable of estimating forces acting on the cervical spine during cycling.

METHOD:

Data Collection: Nine male subjects were evaluated voluntarily on bicycles attached to a magnetic cyclo-simulator Cateye CS1000, pedaling at a cadence of 80 rpm (gear ratio 53x17), in common cycling postures and in the upright neutral posture (Figure 1). Each posture was maintained for one minute, being the EMG of the cervical extensors and the kinematic data (sagittal images of the spine) recorded during the last 15 seconds.

(a) (b) (c) (d)
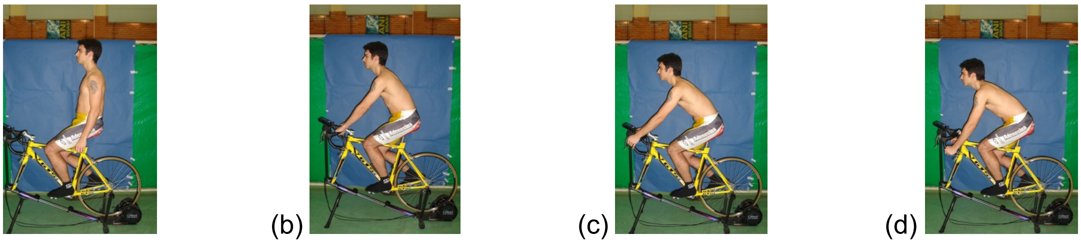
Figure 1: Analyzed postures: (a) upright neutral, (b) rest, (c) intermediate e (d) attack.

To obtain the EMG data, one 16 channel electromyograph (EMG System of Brazil Ltda, São Paulo) was used. The electromyograph have a common mode reject (CMR) of 115 dB (at 60 Hz), a gain of 1000x and a noise of 4.5 μV rms (10 Hz – 3 kHz). The signals were obtained using AqDados software and an A/D converter (Lynx Electronic Technology Ltda), with a sampling frequency of 1000 Hz. Electrodes (Ag/AgCl, diameter 2.2 cm) were used, disposed bilaterally on the intersection point between the line C7-ear and the line of action of the splenius capitis, according to Joines et al. (2006). For the normalization of the EMG, a 5 second maximum voluntary isometric contraction (MVC) was performed in the neutral position.

For the acquisition of the kinematic data, one JVC GR-DVL 9800 digital camera of 50 Hz was used, with its optic axis perpendicular to the subjects (sagittal plane) and illumination directed for a reflecting equipment. Reflective markers were placed on the following anatomical points: manubrium sternii, laryngeal prominence, mental protuberance, tragus, head of the jaw, vertex, external occipital protuberance and spinous processes of C1, C4 and C7.

In order to locate the center of the vertebral body and of the spinous process of C7, one subject was submitted to x-ray exams (focal distance of 1150mm), in the sagittal plane, (1) in the upright neutral posture and (2) in the cervical extension (attack posture), with lead markers placed on the same anatomical points previously mentioned.

Data Analysis: The EMG signal was processed using SAD32 software (version 2.61.07mp; www.ufrgs.br/lmm) with a 20 Hz Butterworth digital high pass filter and root mean square (RMS) at intervals of 40 ms (Hamming). The images were digitized using DVideow (Pascual et al., 2006). The muscular force of the cervical extensors (MF_R) was estimated through the inverse dynamics technique, adapting the theoretical biomechanical model of the cervical spine (*TBC*), which considers the head and the neck as a rigid segment with a curvilinear format, with a rotation axis located at the center of the vertebral body of C7 (Dulhunty, 2001). Three forces are involved, the MF_R originating at the external occipital protuberance and directed towards the spinous process of C7, the weight force (W) that acts at the head center of mass (CM) and the articular force (AF_R), that acts at the rotation axis. The free body diagram from the *TBC* model is presented in Figure 2.

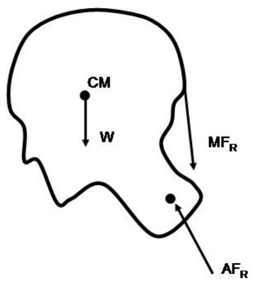

Figure 2: Free body diagram from the biomechanical model of the cervical spine.

The mass parameters and the center of mass were taken from the anthropometric tables (Dempster, 1955). For the analysis of the internal forces, specific routines were elaborated in a MATLAB® environment.

TBC was considered to move in agreement with the movement equations: of translation of the mass center, following the 2nd Law of Newton and of rotation, following the Euler principle.

The statistical analysis was accomplished through the SPSS 13.0 software. The comparison of the four postures was made using the mean MF_R and RMS values. The Shapiro-Wilk and of Mauchey tests were used to check, respectively, the normality and the spherical aspect of the data. The ANOVA for repeated measures was employed to verify differences between the postures, and the Post Hoc's Test Bonferroni was used to locate the differences. The significance level adopted was of 0.05.

RESULTS:

The results demonstrated that the behavior of the MF_R and RMS values of the cervical extensors were similar, increasing from the upright to the attack position. When the cycling postures were analyzed, higher MF_R and RMS values were found in the intermediate and the attack positions (Figure 3).
In all postures analyzed, there were significant differences ($p<0.01$) in both the MF_R, and the RMS values.

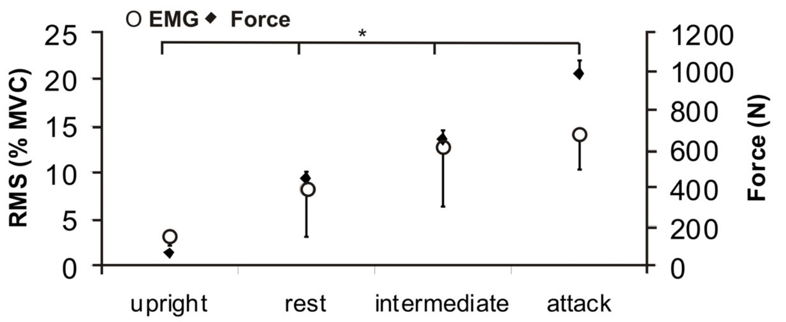

Figure 3: Mean and standard deviation of MF_R and RMS.

DISCUSSION:

Biomechanical models can be used for analyses of the cervical spine, especially when considered the difficulty to make direct measurements in this area (Vasavada, Li & Delp, 1998), in function of the anatomical characteristics, technological limitations and ethical restrictions. However, it is necessary to emphasize that these models are built starting from simplifications of the reality, needing comparisons with the literature (Snijders, Hoek & Roosch, 1991), which makes it difficult due to the lack of existent biomechanical studies investigating the cervical spine *in vivo* (Adams & Dolan, 2005).
The present model found higher magnitudes of MF_R in the postures of rest, intermediate and attack, when compared to the upright neutral posture, and in the intermediate and attack postures, when compared to the rest posture (Figure 3). The passage of the upright neutral for rest posture caused an increase of 85% in the average of MF_R. When the change was from the rest posture to the intermediate, the increase was 30.7%. When passing from the intermediate to the attack posture, the values increase 35.5%. A pattern of similar behavior was observed for the RMS value, however, with an increase in smaller proportion of the intermediate to the attack posture (Figure 3).
One explanation for the increase of MF_R and RMS values is stated in the fact that as the posture is modified alteration of the weight moment arm (MA_W) and muscle force moment arm (MA_M) occurs. When the head becomes more forward and extended, MA_W increases, causing the elevation of the flexor moment. To compensate the superior magnitude of the flexor moment, in order to maintain the system in rotational balance, and considering that MA_W decreases with the posture alterations, being smaller in the attack posture, an increase in the muscle extensor moment happens, promoted thanks to a magnitude increase of the force generated by the cervical extensor muscles.
Those results are confirmed based in the study of Vasavada, Li & Delp (1998). His research demonstrated that in superior extensions to 20º, the MA_M and the capacity of force generation of some extensor muscles of the cervical decrease appreciably, especially the semispinalis and splenius muscles that have great capacity in the upright neutral posture. This also explains the increase in smaller proportion of the RMS value between the intermediate and attack postures, once the positioning of the electrodes reflects mainly the activity of the splenius, practically the only muscle with real participation in the cervical extension accessible in surface EMG (Joines et al., 2006).
Snijders, Hoek & Roosch (1991), also observed superior magnitudes of the muscular force in extension, when compared to the upright neutral posture. Harisson et al. (2001), affirmed

that the force generated by stabilizers cervical and head muscles, as the splenius, tends to increase the compression in the tissues of the spine, what could cause the precocious degeneration and consequently injury and pain in the spine regions (Adams & Dolan, 2005).

CONCLUSION:

During cycling, especially in aerodynamic postures when the support of the hands is made in the lower areas of the handlebar, there is an increase of MF_R. This fact occurs as result of an increase of weight moment and a decrease of MA_M. Besides, these results esteem for the biomechanical model were reinforced for an elevation in the muscle activity find in these postures. This condition suggests a strong relationship among the cycling, the adopted posture in the bicycle and the origin of the pain in areas of the spine.

REFERENCES:

Adams, M.A. & Dolan, P. (2005). Spine biomechanics. *Journal of Biomechanics*, 38, 1972-83.

Burnett, A. et al. (2004). Spinal kinematics and trunk muscles activity in cyclists: a comparison between healthy controls and non-specific chronic low back pain subjects – a pilot investigation. *Manual Therapy*, 9, 211-19.

Dempster, W.T. (1955). Space Requiments of the seatd operator. *WADC Technical Report (TR- 55-159).* Ohio: Wrigth-Patterson Air Force Base.

Dulhunty, A. (2001). Simpified conceptual model of the human cervical spine for evaluating force transmission in upright static posture. *Journal of Manipulative and Physiological Therapeutics*, 25, 306-17.

Harisson, D.E. *et al*. (2001). Comparison of axial and flexural stress in lordosis and three buckled configurations of the cervical spine. *Clinical Biomechanics*, 16, 276-84.

Joines, S.M.B. *et al.* (2006) Low-level exertions of the neck musculature: a study of research methods. *Journal of Electromyography and Kinesiology,* 16, 485-97.

Kyle, CR. (1994). Energy and aerodynamics in bicycling. *Clinics in Sports Medicine,* 13, 39-73.

Mellion MB. (1994). Neck and back pain in bicycling. *Clinics in Sports Medicine,* 13, 137-64.

Pascual, J. et al. (2006). Background recovering in outdoor image sequences: an example of soccer players segmentation. *Image and Vision Computing,* 24, 363-74.

Salai, M. et al. (1999). Effect of changing the saddle angle on the incidence of low back pain in recreational bicyclists. *British Journal of Sports Medicine*, 33, 398-400.

Silberman, M.R. et al. (2005). Road Bicycle Fit. *Clinical Journal of Sports Medicine*,15, 271-76.

Snijders, C.J., Hoek, V.D & Roosch, E.R. (1991). A biomechanical model for the analysis of the cervical spine in static postures. *Journal of Biomechanics*, 24, 783-92.

Vasavada, A.N., Li, S. & Delp, S.L. (1998). Influence of muscle morphometry and moment arms on the moment-generating capacity of human neck muscles. *Spine*, 23, 412-22.

Vey Mestdagh, K. de. Personal perspective: in search of a optimum cycling posture. *Applied Ergonomics*, 29, 325-34.