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ORIGINAL RESEARCH

Duration of the effects of spinal manipulation on pain intensity and electromyographic activity of paravertebral parts of individuals with chronic mechanical low back pain

Duração dos efeitos de uma manipulação vertebral sobre a intensidade da dor e atividade eletromiográfica dos paravertebrais de indivíduos com lombalgia crônica mecânica

Duración de los efectos de manipulación vertebral sobre la intensidad de dolor y actividad electromiográfica de la columna en sujetos con dolor lumbar crónico mecánico

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ABSTRACT | The objective of this research was to evaluate the effects of a manipulative intervention on the electromyographic activity of paraverterbral muscles and low back pain intensity, both immediately and 30 minutes after their application in individuals with chronic low back pain. Thirty-eight individuals were evaluated, being randomly divided into two groups: the one who received global vertebral manipulation technique (n=20), and control (n=18), which remained in lateral decubitus for 10 seconds on each side of the body. The electromyographic signal of paravertebral parts at L4-L5 level both right and left was collected during three cycles of flexion-relaxation-extension of the torso. In the intervals between cycles, participants reported the intensity of pain through the Visual Analog Scale (VAS, 100 mm). A significant reduction in pain intensity in the group that received the manipulation was observed, opposed to the control group, in which the score increased in VAS. The dimension of the effect on pain intensity was 1.0 and 0.9 right after the manipulation and 30 minutes later. The flexion/relaxation ratio (FRR) increased in the group that was subjected to manipulation, but remained unchanged in the control group. The FRR displayed effects between the groups that were 0.6 and 0.5 in both assessments. We were able to see effects of the manipulation in these two variables, and its continuation in the range observed, concluding that they linger at least during that time.

Keywords | Low Back Pain; Spinal Manipulation; Electromyography.

RESUMO | O objetivo desta pesquisa foi avaliar os efeitos de uma intervenção manipulativa sobre a atividade eletromiográfica dos músculos paraverterbais e a intensidade da dor na coluna lombar imediatamente e 30 minutos após sua realização em indivíduos com dor lombar crônica mecânica. Foram avaliados 38 indivíduos, distribuídos aleatoriamente em dois grupos: o que recebeu a técnica de manipulação vertebral global (n=20) e o controle (n=18), que permanecia em decúbito lateral por dez segundos sobre cada lado do corpo. O sinal eletromiográfico dos paravertebrais ao nível L4-L5 direito e esquerdo foi coletado durante três ciclos do movimento de flexão-relaxamento-extensão do tronco. Nos intervalos entre os ciclos, os participantes relataram a intensidade de dor através da Escala Visual Analógica (EVA 100 mm). Foi observada redução significativa na intensidade da dor no grupo que recebeu a manipulação, ao contrário do grupo controle, em que a pontuação na EVA aumentou. O tamanho do efeito na intensidade da dor foi de 1,0 e 0,9

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logo após a manipulação e 30 minutos depois. A razão de flexão/relaxamento (RFR) aumentou no grupo que foi submetido à manipulação, mas permaneceu inalterada no grupo controle. A RFR exibiu tamanhos de 0,6 e 0,5 entre os grupos nas duas avaliações. Foi possível constatar efeitos da manipulação nessas duas variáveis e sua continuidade no intervalo observado, concluindo-se que eles perduram pelo menos durante esse tempo.
Descritores | Dor Lombar; Manipulação da Coluna; Eletromiografia.

RESUMEN | En este estudio se evalúan los efectos de intervención manipulativa sobre la actividad electromiográfica de los músculos paravertebrales y la intensidad del dolor lumbar inmediatamente y treinta minutos después de realizada la actividad por sujetos con dolor lumbar crónica mecánica. Participaron 38 sujetos, los cuales fueron divididos al azar en dos grupos: el que había recibido la técnica de manejo vertebral global (n=20) y el grupo control (n=18), lo cual había permanecido en posición lateral por diez segundos sobre cada lado del cuerpo. Se recolectó el signo electromiográfico de los paravertebrales al nivel L4-L5 derecho e izquierdo durante tres ciclos de movimiento de flexión-relajamiento-extensión del tronco. Entre los intervalos de los ciclos, los participantes relataron la intensidad de dolor mediante la Escala Visual Analógica (EVA 100 mm). Los resultados mostraron una significativa disminución en la intensidad de dolor en el grupo que había recibido el manejo, mientras que el grupo control aumentó el puntaje de EVA. El efecto de la intensidad de dolor fue de 1,0 y 0,9 tras el manejo y treinta minutos después. La razón flexión/relajamiento (RFR) aumentó en el grupo al que se sometió al manejo, mientras que había permanecido inalterable en el grupo control. Los valores de los efectos de la RFR entre los grupos fueron de 0,6 y 0,5 en las dos evaluaciones. En estas dos variables se constataron efectos de manejo, que había seguido en el intervalo observado, lo que muestra su permanencia por lo menos durante el periodo.
Palabras clave | Dolor Lumbar; Manipulación Espinal; Electromiografía.

INTRODUCTION

Low back pain is the most common cause of incapacity for people under 45 years old, and the second most common reason for first-contact professional appointments, as chiropractors and osteopaths[1], who use high-speed spinal manipulation techniques as a conservative approach in the treatment of musculoskeletal disorders[2,3].

Some studies have reported positive results from spinal manipulation such as improving joint mobility, decreasing pain and muscle spasms[2,4,5]. The physiological mechanisms responsible for these effects are not yet fully clear[2,3,6], but are related to the inhibition of the electrical activity of paravertebral muscles. This is because individuals with low back pain often do not exhibit the flexion-relaxation phenomenon[7], i.e., paravertebral electromyographical activity does not stop when they reach the full flexion, the opposite that occurs with individuals without the pathology[8]. Such increased electrical activity in the phase of relaxation would be a protective mechanism, because it stabilizes the structures involved, preventing other injuries[8]. It could be related to the structural changes of paravertebral muscles of people with chronic low back pain, such as changes in the proportion of type I and II fibers[9].

Works that have studied the immediate effects of the manipulation in subjects with low back pain, observed a decrease of electromyographic activity when the individual is in full flexion of the trunk immediately after the intervention[5,10]. These studies researched only the immediate effects of vertebral manipulation and how long they could endure is unknown. To contribute in this sense, the objective of this study was to analyze the effects of a high-speed manipulative intervention on pain intensity and the electromyographic activity of paravertebral muscles in patients with chronic low back pain in a horizon of 30 minutes after application of the manipulation.

The hypothesis proposed here is that the effects of the manipulation in pain intensity and electromyographic activity should continue in the range observed (30 minutes).

METHODOLOGY

The research was approved by the Ethics Committee from Pontifícia Universidade Católica of Paraná (PUCPR). Individuals showing chronic mechanical low back pain for at least six months without receiving any treatment were recruited[11], who were in the waiting list for treatment in the physiotherapy clinic school of

PUCPR. Individuals with radiated pain below the knee, skeletal or neuromuscular disorders identified by MRI or x-ray, and those who showed signs called "red flags" were excluded[12].

Forty volunteers were selected randomly and separated into control (C) and manipulation (M) groups. A box containing 20 numbers "1" and 20 numbers "2" was used. The volunteers who fulfilled the inclusion requirements of the research drew a number to establish to which group they would belong. They were then submitted to an initial evaluation comprised by medical history, physical evaluation, and Rolland-Morris' questionnaire[13]. Electromyographic signals from two volunteers of the control group had to be eliminated from the analysis, because they were hopelessly compromised by artifacts. Therefore, Group C featured 18 subjects (3 men and 15 women) and Group M featured 20 subjects (5 men and 15 women). Group C was 44.3±8.6 years old, pain period of 7.1±7.3 years, and the score in Rolland-Morris questionnaire of 10.3±5.2. The age of Group M was 37.9±9.8 years old, their pain period was of 8.9±7.5 years, and the questionnaire score was of 8.5±4.3. There was no difference between the groups regarding these parameters.

Group M received a global bilateral high-speed vertebral manipulation of the pelvis[14], while volunteers in group C remained in prone position to the right and to the left for ten seconds each[10,15], without any intervention. Spinal manipulation applied in group M was carried out as follows: the physical therapist placed a low back rotation parameter until the tension reflected over L5, then supported the forearm in the sacroiliac joint to make a pressure upwards and in the posterior-anterior direction. At the end of these parameters, a short and quick manipulative thrust was applied, aided by a kick of the leg of the physical therapist[23] (Figure 1). The vertebral manipulations were performed by an osteopathy specialist physical therapist with more than 5 years of experience.

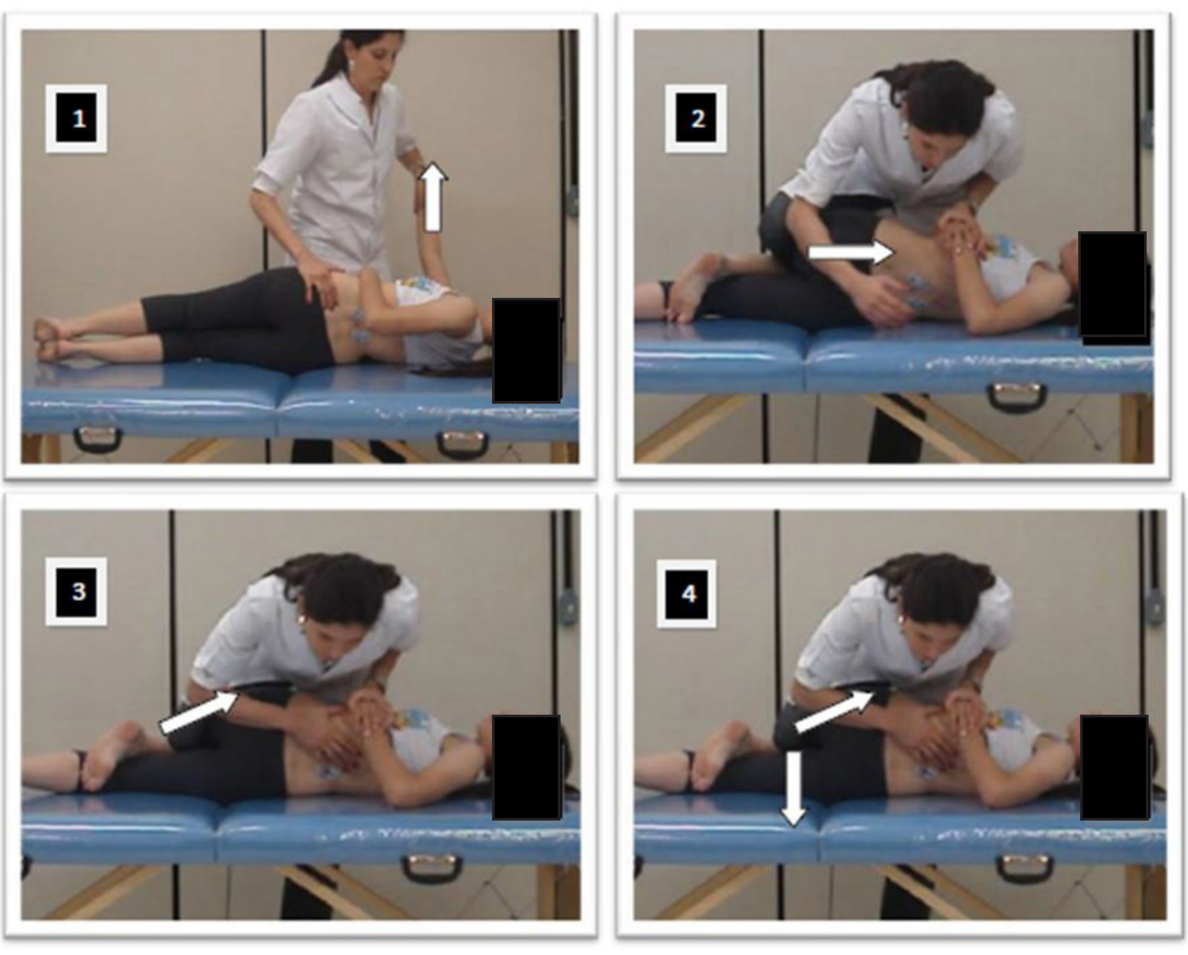

Figure 1. Global spinal manipulation applied in manipulative group. 1. Low back rotation up to L5. 2. Forearm support on the sacroiliac joint towards the head. 3. Posterior-anterior forearm pressure. 4. Manipulative thrust

Electromyography (EMG) signals and the intensity of pain were collected in three moments: pre, post, and after 30 minutes of operation. The signs were collected during the flexion/extension movement of the torso in 3 phases: flexion, extension, and relaxation. For that, the volunteers started off from the standing position with their feet separated in the shoulder distance, and were asked to perform a bending of the torso for 3 seconds, keeping their knees extended, keeping the maximum flexion for 3 seconds (relaxation), and return to the initial position in 3 seconds (extension). The verbal command was used with the help of a timer to control the movement[5,17]. Three cycles were carried out with 1 minute of rest between them. At the end of each cycle, the volunteers marked the perception of pain in visual analogue scale (VAS-100 mm). Before that procedure a training was performed with the volunteers with three attempts each[5,17]. In a day before the data collection the test of Biering-Sorensen[18] was conducted to obtain the EMG values during maximum voluntary contraction (MVC).

The procedures were performed by two researchers. The first researcher was blind to the composition of the groups and was responsible for collecting the EMG and VAS, and the other for the implementation of the manipulations.

To capture the EMG signals, two pairs of self-adhesive bipolar electrodes with Ag/AgCl surface, 1 cm diameter (Kendal Meditrace, Canada) were stuck to paravertebral muscles on the right and the left side at the L4-L5 level, after shaving and cleaning with alcohol. The electrodes were placed at 20 mm laterally to the spine process, with a distance between the centers of 20 mm. During the sticking of the electrodes, the volunteers kept their torso semi-flexed. The reference electrode was stuck to the styloid process of the ulna of the right upper limb. Scanning was performed with an electromyograph (EMG System do Brasil® 800 C), 2000 gain, and a band-pass filter between 10 and 500 Hz connected to a signal acquisition board (National Instruments, model USB-6221).

LabVIEW Signal Express 3.0 software was used to scan the signals at 1 kHz and filter them with Butterworth filter of 4th order, band-stop filter between 59 and 61 Hz. The addition of this filter was required to eliminate the 60 Hz noise of the mains. The signals were then processed by software developed in Matlab environment that would smoothen the signals by calculating the RMS values in mobile windows of 1s, with separate centers for 1ms. The maximum values of that RMS envelope, at each stage, were identified automatically by the software, their values were normalized with respect to the signal obtained in the MVC. The average of the left and right muscles was calculated and that value was used as a measure of muscle electrical activity. The flexion-relaxation (FRR), relaxation-extension (RER) and extension-flexion (EFR) ratios were obtained by dividing the maximum of the RMS envelope from one stage by the other[19,29].

To check the normality of the data, the Shapiro-Wilk test was used. Due to the non-normality of the data the ANOVA analysis of Friedman was used for comparison between moments, and the Mann-Whitney U test was used for comparison between groups. The significance level was 0.05, and the Statisca v. 7.0 software was used. When ANOVA indicated a difference, the Wilcoxon test would be performed to compare the moments two by two, with a significance level of 0.016, due to the Bonferroni correction. In situations in which significant differences were found between the groups, the size of the effect was estimated[21].

RESULTS

Figure 2 shows the values of the intensity of pain in every moment. The M group had a reduction in pain intensity as Group C had an increase. A difference was detected between the groups in the POST and POST30 ($p=0.007$ and $p=0.002$) moments, but not at the PRE ($p=0.251$) moment. The dimension of the effect on the difference between the groups in the POST moment was 0.9, and the POST30 moment was 1.0.

The electromyographic activity values are shown in Table 1. The FRR and RER increased significantly after the intervention for Group M, and there was no change in Group C, as shown in figures 3 and 4. EFR values remained unchanged after the manipulation for the two groups, and there was no difference between them observed.

We found significant differences in group M regarding the relaxation phase. The Wilcoxon test showed that both for RER and FRR the differences happen between the pre and immediate post moments, and between pre and post 30 minutes. There was no difference between the groups in RER values in any moment and pre FRR intervention. After the intervention, FRR values of the control group were smaller than those of the study both in the immediate post moment ($p=0.048$), and post 30 min (0.035). The size of the effect on the difference between the groups in the FRR POST moment was -0.6, and at the POST30 moment it was -0.5.

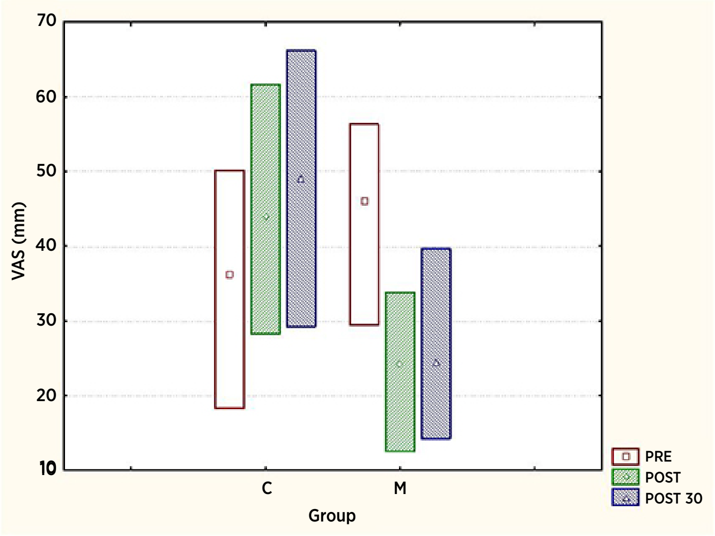

Figure 2. Values of the medians and inter-quartiles range of the Visual Analog Scale (VAS) for groups C (control) and M (that was manipulated) in the three moments (PRE, POST and POST 30). Differences were found between the three moments in the case of group C (p=0.005) and the M group (p=0.000). Comparing the individual moments, there was a difference between the pre moment and the other two moments, but not among these

Table 1. Maximum values of the RMS envelope of the electromyography (EMG) signal in each stage normalized by the maximum voluntary contraction (MVC). Values expressed as median (Q1-Q3), being the first quartile Q1 and Q3 the third quartile of the distribution of data

Phase-Group	RMS_{MAX} PRE (%of MVC)	p Value between groups	RMS_{MAX} POST (%of MVC)	p Value between groups	RMS_{MAX} POST 30min (%of MVC)	p Value between groups
Flexion-C	40.9 (38.2 - 68.7)	0.372	37.4 (31.8 - 54.1)	0,918	40.2 (33.6 - 49)	0.473
Flexion-M	38.4 (33.7 - 61.5)		43.4 (31.1 - 57.1)		36.7 (27.2 - 65.7)	
Relaxation-C	29.2 (9.4 - 53.4)	0.661	33.4 (13.2 - 61.4)	0.169	35.9 (11.3 - 58.1)	0.084
Relaxation-M*	23.2 (10.3 - 49.4)		15.2 (6.3 - 52.8)		10.2 (5.5 - 43.8)	
Extension-C	65.4 (62.0 - 86.7)	0.404	68.6 (62.5 - 88.5)	0.558	63.5 (59.1 - 85.6)	0.598
Extension-M*	79.5 (65.1 - 99.4)		76.6 (64.1 - 99.7)		74.0 (58.7-94.3)	

Note: C means control group and M is the group that underwent manipulation. Symbol (*) indicates there was a difference between the moments within the same group. No statistically significant difference was observed in the comparison between the groups

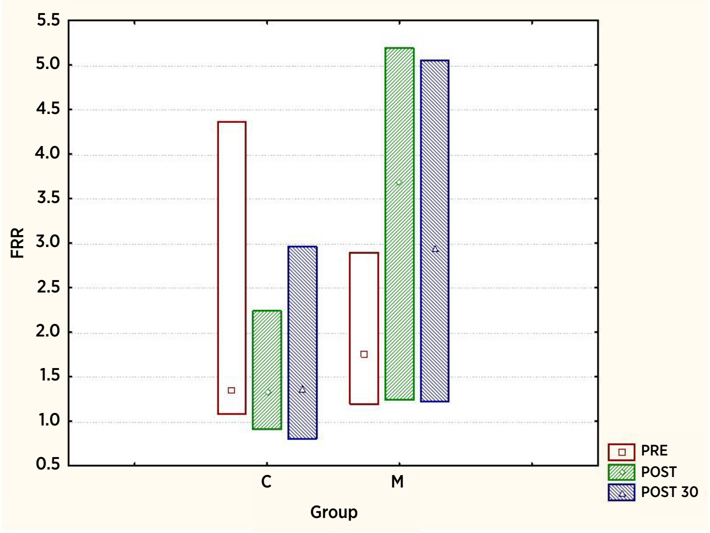

Figure 3. Median values and interquartile range of FRR for groups C and M in three moments (pre, post, and post 30). There was no difference between the moments in Group C (p=0.128), but there was a difference in Group M (p=0.000). Comparing the individual moments, difference between the pre and the other two moments, but not between those

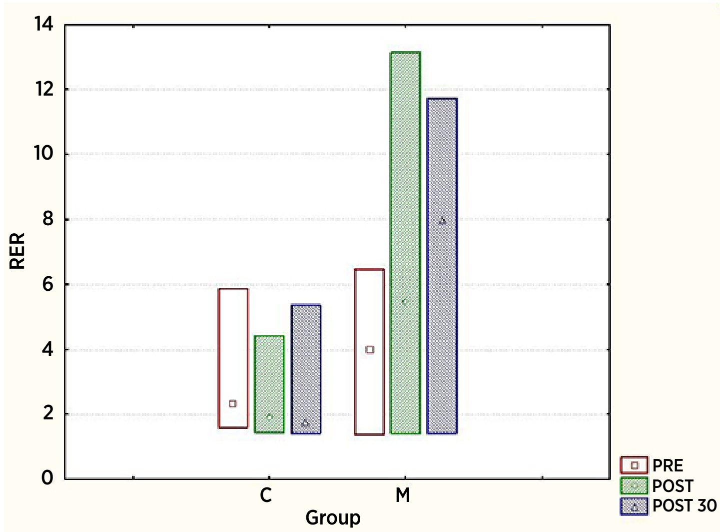

Figure 4. Median values and interquartile range of RER for groups C and M in three moments (pre, post, and post 30). There was no difference between the moments in Group C (p=0.030) and also in Group M (p=0.004). Comparing the individual moments, in Group M there was a difference between the pre moment and the other two moments, but not among these. In Group C, the only difference observed was between the pre and post 30 moments

DISCUSSION

The results obtained in the three moments within the group for pain intensity (Figure 2), to the maximum value of the electromyographic signal in relaxation phase (Table 1), and for the FRR and RER ratios (Figures 3 and 4), indicate that the changes have endured during the three evaluations. However, contrary to what was expected, only the score on VAS and FRR exhibited significant differences between the two groups.

Regarding the intensity of the pain, its decrease in group M and its increase in group C here observed also occurred in the studies of Lalanne et al.[7] and Bicalho et al.[5] considering that in the three studies the individuals in the control group remained lying in lateral decubitus for 10 seconds. But here, besides finding a decrease in pain in the immediate revaluation, it is possible to realize that in group M analgesia was maintained for a period of 30 minutes. A limitation of this study is the fact that group M is already in a level of pain larger than group C before manipulation, having the greatest potential for improvement. However, the fact that there has not been any improvement, but increased pain in group C, suggests that the results are really due to the manipulation.

In the relaxation phase data shows that manipulation was able to reduce the electromyographic activity of paravertebral muscles in total trunk flexion position in group M. That was the expected result, and it agrees with several other studies in literature[5,14,15,22], despite some methodological differences. Consequently, the reasons involving the static phase of relaxation also suffered changes (FRR and RER), even with the reduction of electromyographic activity during extension. However it is necessary to emphasize that there was no difference between the groups for maximum RMS amplitude values, even if the behavior of the two groups individually has been different. The inability to see difference between the groups was probably a result of the great dispersion of signal amplitude variables of EMG.

The immediate post and post 30 minutes values of FRR have increased in Group M, possibly due to decreased electromyographic activity during the relaxation phase, as expected. Among the electromyographic variables investigated, that was the only one that showed a difference between the groups. In fact, the FRR has been used to distinguish individuals with or without low back pain[19] as well as to check the efficiency of therapeutic interventions[5,15,17], thus being a clinically more relevant indicator regarding the the effectiveness of therapeutic interventions. Lalanne et al.[7] and Bicalho et al.[5] also report a sharp increase of FRR after low back manipulation. Other researchers have found an increase in the FRR after approaches in different treatments[10,17]. The contribution of this work was to note that, in addition to the acute increase of the FRR, there has also been a maintenance of that effect after 30 minutes.

The results of that study were similar to the ones of Ritvanen et al.[15] and Bicalho et al.[5], who believe that manipulative procedures have a tendency to produce reflex inhibition of electromyographic activity of paravertebral muscles in the relaxation phase. So, it seems clear that spinal manipulation is able to increase FRR, since the values of the electromyographic activity of the flexion phase have not been modified, but those of the relaxation phase decreased, motivating new studies to clarify the mechanisms behind this increase.

On the values of the relaxation/extension ratio (RER) we observed changes in the post and post 30 minutes moments. Similar results were found in studies from Lehman and McGill[14]; Devotch et al.[22]; and Ferreira et al.[6], which have showed that the inhibition of acute manipulations generates electromyographic activity of paravertebral muscles in static or relaxation situations, changing the RER or FRR as showed, since that ratio involves one of the static phases.

No significant change occurred in the EFR after spinal manipulation. In group C, this result is due to no change in the electromyographic activity dynamic phases (flexion and extension). In the case of group M, a reduction of electromyographic activity in extension phase was not enough so there was a change in EFR. That result agrees with Ritvanen et al.[15] and Bicalho et al.[5], who did not find significant differences in the EFR after the therapeutic interventions.

The values of the size of the effect relating to the difference between the two groups for both the VAS and FRR reveal that the intervention effect is stronger on the first variable when compared to the second one.

One limitation of the study is the absence of an effective placebo or sham group to identify the placebo effect regarding the expectation of the volunteer and the manual contact of the therapist. For being such a transversal study without the intent to treat pain, the results have very limited validity from a clinical point of view. To investigate the results of manipulation as a treatment it would be necessary to establish a clinical protocol with repetition of the maneuver on the same day or in several days. The results reported here might assist in the definition or the analysis of a clinical protocol of that nature.

CONCLUSION

High-speed manipulative intervention applied in this study was able to promote a decrease in pain intensity (measured by VAS) and increased flexion-relaxation ratio (FRR), and these effects were kept for the 30 minutes in which observation lasted.

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REFERENCES

1. Schneider MJ, Brach J, Irrgang JJ, Abbott KV, Wisniewski SR, Delitto A. Mechanical Vs Manual Manipulation for low back pain: an observational cohort study. J Manipulative Physiol Ther. 2010;33(3):193-200. doi: 10.1016/j.jmpt.2010.01.010.
2. Maigne J, Vautravers P. Mode dáction dês manipulations vertébrales. Rev Rhum. 2003;70:713-9. doi:10.1016/S1169-8330(03)00158-3
3. Ernest E. A systematic review of systematic reviews of spinal manipulation. J R Soc Med. 2006;99(4):192-6. doi: 10.1258/jrsm.99.4.192
4. Pickar JG. Neurophysiological effects of spinal manipulation. Spine J. 2002;2:357-71. doi: http://dx.doi.org/10.1016/S1529-9430(02)00400-X
5. Bicalho E, Setti JAP, Macagnan J, Cano JLR, Manffra EF. Immediate effects of a high-velocity spine manipulation in paraspinal muscles activity of nonspecific chronic low-back pain subjects. Manual Ther. 2010;15(5):469-75. doi: 10.1016/j.math.2010.03.012.
6. Ferreira ML, Ferreira PH, Hodges PW. Changes in postural activity of the trunk muscles following spinal manipulative therapy. Manual Ther. 2007;12:240-8. doi:10.1016/j.math.2006.06.015.
7. Lalanne K, Lafond D, Descarreaux M. Modulation of the flexion-relaxation response by spinal manipulative therapy: a control group study. J Manipulative Physiol Ther. 2009;32(3):203-9. doi: 10.1016/j.jmpt.2009.02.010.
8. Neblett R, Mayer TG, Gatchel RJ, Keeley J, Proctor T, Anagnostis C. Quantifying the lumbar flexionrelaxation phenomenon: theory, normative data and clinical applications. Spine. 2003; 28(13):1435-46. doi: 10.1016/j.jmpt.2014.07.003.
9. Colloca CJ, Hinrichs RN. The biomechanical and clinical significance of the lumbar erector spinae flexion_relaxation phenomenon: a review of literature. J Manipulative Physiol Ther. 2005;28(8):623-31. doi:10.1016/j.jmpt.2005.08.005
10. Demoulin C, Crielaard J, Vanderthommen M. Spinal Muscle Evaluation in Healthy Individuals and Low-Back-Pain Patients: a Literature Review. Joint Bone Spine. 2007;74:9-13. doi:10.1016/j.jbspin.2006.02.013
11. Walker BF, Williamson OD. Mechanical or inflammatory low back pain. What are the potential signs and symptoms. Manual Ther. 2009;14(3)314-20. doi: 10.1016/j.math.2008.04.003.
12. Koes BW, Tulder MWV, Thomas S. Diagnosis and treatment of low back pain. BMJ. 2006;332:1430-4. doi:10.1136/bmj.332.7555.1430.
13. Nusbaum L, Natour J, Ferraz MB, Goldenberg J. Translation, adaptation and validation of the Roland-Morris ques-

tionnaire – Brazil Roland-Morris. Braz J Med Biol Res. 2001;34(2):203-10. doi: http://dx.doi.org/10.1590/S0100-879X2001000200007.

14. Lehman GJ, McGill SM. Spinal manipulation causes variable spine kinematic and trunk muscles electromyographic responses. Clin Biomech. 2001;16(4):293-9. doi: http://dx.doi.org/10.1016/S0268-0033(00)00085-1

15. Ritvanen T, Zaproudina N, Nissen M, Leinoven V, Hannine O. Dynamic surface electromyographic responses in chronic low back pain treated by traditional bone setting and conventional physical therapy. J Manipulative Physiol Ther. 2007;30(1):31-7. doi:10.1016/j.jmpt.2006.11.010.

16. Ricard F. Tratamiento osteopatico de las lumbalgias y ciaticas. Madrid: Panamericana, 1998.

17. MarshalP, MurphyB. Changes in the flexion relaxation response following an exercise intervention. Spine. 2006a;31(23):877-83. doi: 10.1097/01.brs.0000244557.56735.05

18. Biering-Sorenson. Physical measurements as risk indicators for low back trouble over a one-year period. Spine. 1984;9(2):106-119, 1984.

19. Watson PJ, Phil CKBM, Main CJ, Chen ACN. Surface electromyography in the identification of chronic low back pain patients: the development of the flexion relaxation ratio. Clin Biomech. 1997;12(3):165-71. doi: http://dx.doi.org/10.1016/S0268-0033(97)00065-X

20. Ambroz C, Scott A, Ambroz A, Talbott EO. Chronic low back pain assessment using surface electromyography. J Occup Env Med. 2000;42(6):660-9.

21. Cohen J. Statistical power analysis for the behavioral sciences. 2. ed. New Jersey: Lawrence Erlbaum Associates, 1988.

22. Devotch JW, Pickar JG, Wilder DG. Spinal manipulation alters electromyographic activity of paraspinal muscles: a descriptive study. J Manipulative Physiol Ther. 2005;28(7):465-571. doi:10.1016/j.jmpt.2005.07.002.