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Effects of vibration therapy in the musculoskeletal system in post-surgical breast cancer women: longitudinal controlled clinical study

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Abstract **Introduction:** The biomechanical changes that arise after breast cancer increase the need for new rehabilitation programs. The aim of this study was to evaluate medium- and long-term effects of vibration therapy on pain intensity, range of motion, myoelectric activity, and muscle strength of post-surgical breast cancer women. **Methods:** This controlled longitudinal clinical study was composed of 14 breast cancer women, who underwent vibration therapy treatment (VTG), and 14 healthy women, who constituted the control group (CG). The VTG performed ten 15-minutes sessions of vibration therapy on their affected upper limb. The volunteers were evaluated before and after treatment protocol, and three months later. **Results:** We observed an attenuation of pain intensity after vibration therapy ($p < 0.0001$) and significant increase in range of motion during extension, abduction, and adduction movements of the horizontal shoulder. We noticed a trend in the reduction of compensatory movements, which activated the muscle contraction mechanism. The scapular dynamometer values for shoulder strength were significant. The VTG had less muscle strength than the CG in all situations: before treatment ($p < 0.0001$), after treatment ($p = 0.0024$), and 3 months later ($p = 0.0008$). The VTG increased muscle strength after treatment ($p = 0.0005$) and 3 months later ($p = 0.0006$). **Conclusion:** Vibration therapy attenuated pain symptoms, improved shoulder movements, activated muscle contraction mechanism, and increased shoulder strength, which may be benefits of the conducted physical therapy.

Keywords: Breast cancer, Vibration therapy, Pain, Range of motion, Muscle activation, Muscle strength.

Introduction

Breast cancer is considered a disease of great importance in health-care services, so prevention and control measures have been adopted to promote positive changes in its population scenario. Breast cancer is the leading cause of death due to cancer in the female population of developing countries. According to the Brazilian *Instituto Nacional do Câncer* (INCA), the survival of these patients has increased about 50% to 60% over the past 40 years (Brasil, 2014).

Currently there are two options of treatment, 1) conservative therapy that includes breast lumpectomy or local excision followed by dissection of the lymph nodes with or without performing radiotherapy; 2) or mastectomy, which consists of excision of all breast tissue, and is divided according to axillary and muscle dissection (Tovar et al., 2014).

Regardless of the surgical technique chosen, other therapeutic modalities are associated with both treatments, such as chemotherapy, radiotherapy, and endocrine therapy. These methods lead to the development of biomechanical changes in the shoulder joint, mainly due to intense pain, muscle weakness, restriction of movement, among other physical disabilities that can occur from 12 months to 3 years later (Londen et al., 2014; Springer et al., 2010).

Pain is a high impact factor on the psychological, social, and physical health, added to the primary impairments related to cancer and surgical interventions (Walczyńska-Dragon and Baron, 2011). Chronic pain is a debilitating clinical symptom, which prevails in 25% to 60% of post-surgical breast cancer women and can last for many years after treatment. Nerve injury is considered an important factor for the development of chronic pain and is responsible for triggering neuropathic pain, local sensitization, and hyperalgesia, mainly in breast area of the ipsilateral limb and cervical-thoracic region (Hadi et al., 2012).

Disorders that involve the shoulder joint and surgery ipsilateral upper limb affect about 70-80% of women and are common in clinical practice. Movements of flexion and abduction are the most affected, instigate reduction of function, and muscle activation mechanisms, probably because of pain, neurological, and muscular affections (Xu et al., 2014).

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Muscles in the shoulder girdle are responsible for providing stability and mobility to the scapula. Deltoid and rotator cuff muscles provide compressive force to the glenohumeral joint, preventing the humeral head from improper movement, and scapulothoracic muscles that are involved in humerus abduction assist them. The imbalance between these muscles may induce movement disorders of the glenohumeral joint and cause joint instability and imbalance in muscle activity, which may affect other muscles (Jung and Moon, 2015).

Thus, rehabilitation programs should be carried out early to prevent functional limitations. Multiple therapeutic resources can be used for this purpose, such as manual lymphatic drainage (Martín et al., 2011), kinesiotherapy (Mutrie et al., 2012.), skin care (Rodrick et al., 2013.), pneumatic compression and compression bandages (Atalay et al., 2015; Stout et al., 2012), and the vibration therapy (Mendes et al., 2014; Souza et al., 2014).

Based on neurophysiological mechanisms, vibration therapy is responsible for promoting normal patterns of motor activity due to modulation of the excitability of motor neurons and corticospinal tract. The generated mechanical stimuli are transmitted through neural networks, which stimulate muscle spindles and sensory receptors in the muscle belly, which, in its turn, may influence the muscle contraction mechanism and somatosensory stimulation (Mikhael et al., 2010).

Recent studies recommend the use of vibration therapy to relieve manifestations of pain and functional impairment (Aman et al., 2015; Yang and Seo, 2015), attenuate of muscle tension and muscle soreness (Veqar and Imtiyaz, 2014), fix neurological disorders (Silva et al., 2011), improve balance and proprioception (Martínez et al., 2013) and improve cardiovascular conditions (Naghii et al., 2012).

Considering the benefits of vibration therapy reported in previous studies, we believed that it could help to minimize pain symptoms, improve range of motion and strength, and promote muscle synergism in post-surgical breast cancer women. However, there are no studies concerning the use of vibratory stimulation in rehabilitation programs after breast cancer.

Therefore, the aim of this study was to evaluate the medium- and long-term effects of vibration therapy in pain intensity, range of motion, myoelectric activity, and muscle strength in post-surgical breast cancer women.

Methods

This is a longitudinal controlled clinical study conducted in the Laboratório de Engenharia de Reabilitação Sensório Motora at the Universidade do Vale do Paraíba (Univap), after approval by the Research Ethics Committee of the Univap under Protocol CAAE 07694812.7.0000.5501 and the Clinical Trials registry (NCT01893944). All of the individuals signed the informed consent and were informed about the measures taken.

Twenty-eight women participated in this study and were divided into two distinct groups: vibration therapy group (VTG) consisting of 14 post-surgical breast cancer women (mean age = 56.3 ± 10.9 years); and control group (CG) consisting of 14 healthy women (mean age = 50.28 ± 7.40 years). The VTG underwent vibratory therapy and the CG only took part of evaluation protocol with electromyography and dynamometer, in order to give a reference of standard behavior and muscle strength in healthy women.

The calculation of sample size was performed according to the 95% confidence interval and statistical power 73.7%, which considered the 19 patients who met the criteria for inclusion and exclusion in the screening center. The initial population was 19 post-breast cancer women; however, 5 patients did not complete the total number of sessions and were excluded from the study; thus, the total diminished to 14 women by the end of the study.

Inclusion criteria (VTG): women who underwent conservative or not conservative surgery due to breast cancer and axillary lymphadenectomy, over a year prior; age range 40-70 years; who were not performing radiation therapy or chemotherapy and who had no other carcinomas. *Inclusion criteria* (CG): women who had no problems in the shoulder joint.

Initially, we evaluated all volunteers, considering the parameters of pain intensity, range of motion, myoelectric activity, and muscle strength.

All participants of the VTG received in writing some important treatment information about the committed upper limb and guidance on potential factors that could interfere in the study, such as not to perform any physical activity or take part in other treatment parallel to this. Then we applied the treatment protocol comprised of ten consecutive sessions of vibration therapy for 15-minutes. After completion of the treatment, at the eleventh session, we reevaluated all VTG volunteers following the same initial evaluation parameters. Three months after the end of the proposed treatment, the volunteers returned to undergo the same assessment protocol again, aiming to monitor the long-term effects of vibration therapy protocol.

Assessment tools

The assessment tools we use with both volunteer groups were:

Analog Scale of Numerical Pain: It consisted of a numbered horizontal line, 0-10, with the ends indicating "no pain" and "worst possible pain" (Georgiou et al., 2015; Brasil, 2002). The volunteers were instructed to rate the pain within the existing scale value, according to the intensity of their sensation.

Surface electromyography (EMG): The acquisition of the muscle electrical signal was performed by an eight channel electromyography, EMG830 WF model (EMG System do Brasil Ltda®, São José dos Campos/SP/Brasil), with the following technical characteristics: analog-to-digital conversion board (A / D) with 16-bit resolution; bipolar pre-amplified electrode with a differential gain of 20 times, totaling a final amplification of 1000 times; impedance > 10 MOhms, signal-to-noise ratio < 3 μVolts RMS; common mode rejection ratio > 120 dB; analog band-pass filter of 20-500 Hz; sampling frequency set to 2 kHz per channel.

Signals were measured by 10 mm disc-shaped surface Ag/AgCl (silver/silver chloride) electrodes and bipolar active (preamplifier) electrodes that were placed 20 mm apart from center to center. They were placed with fixing disks and tape on the skin after it had been shaved and cleaned with a 70% alcohol cotton swab (International…, 1999).

Surface electrodes were placed in pairs between the motor point and the distal tendon of the biceps, triceps, deltoid (middle fibers), and trapezius (upper fibers), as specified in the Surface- EMG protocol for the Non Invasive Muscle Assessment (Seniam, 2015), following the longitudinal direction of the muscle fibers. The reference electrode was anointed with gel and placed on the styloid process of the ulna on the side contralateral to the member that underwent surgical intervention.

The EMG signals capture consisted of each volunteer standing upright, as they performed a harmonious and comfortable movement of flexion and abduction; they repeated both movements three times, totaling six repetitions for twenty seconds. All recordings were performed in upper limb ipsilateral to the surgical procedure.

Initially, these EMG signals were normalized regarding to amplitude, consisting of the adaptation of signal values in the desired range (min –1, and most 1) by means of the MATLAB® 6.5.1 software (The Mathworks…, 2015), using routine and specific functions.

After normalization, the data were processed by EMGWorks Analysis of Delsys® software (Delsys, 2015), using band pass filter 4th order Butterworth, cutoff frequency set from 20 Hz to 400 Hz for noise elimination.

For data analysis, considering the total collection time of 20 seconds, only excerpts were selected related to muscle contraction, and relaxation periods were excluded, yielding the root mean square RMS - Root Mean Square of each contraction. Data were grouped into a spreadsheet from Microsoft Office Excel® 2013, where rows represent individuals and columns the RMS values, with an average of 3 contractions obtained for each muscle for both flexion and abduction kept for later statistical analysis.

Dynamometry: The measurement of muscle strength was performed using the portable dynamometer scapular EMG System do Brasil Ltda® São José dos Campos/SP/Brasil, dynamometer model scapular DFE021115/200, electromyography, and this was connected to the computer network. The calibration parameters followed were 2,000 Hz sampling frequency and Kgf unit.

The dynamometry test consisted of each volunteer standing upright with shoulders in abduction of 90°, with elbow flexion and both hands holding the device in front of herself. The dynamometer reading was calibrated before each measurement and was triggered when the volunteer was oriented to pull the dynamometer reading, in order to perform the scapular adduction movement and exert maximum isometric strength for 15 uninterrupted seconds. During the test, the volunteer was encouraged by the therapist's verbal command to exert the maximum effort.

The signals obtained from the hand were processed in EMGWorks Delsys ® software. The first two seconds and the last second in relation to the total collecting time were excluded, to obtain the RMS values, which were tabulated in a worksheet for further statistical analysis.

Goniometry: The range of motion (ROM) was measured using a goniometer ISP® brand of clear plastic with two strips of 20 cm and protractor 0° a 360° (degrees), consisting of a fixed arm, swing arm, and axis. The range of motion measurement was performed with volunteer standing upright, considering the movements of flexion, extension, horizontal adduction, and abduction of the ipsilateral side of the surgical procedure. Participants were instructed on which movements should be performed in order to familiarize them with the test. Then they performed the moves actively to complete the entire arc of movement possible. From this angle, the record was made.

Experimental protocol

The study used the vibration blanket developed by the authors, in partnership with Vibra IND. e com. Prod. Electronics LTD, which proposed a prototype for premium members. The vibration blanket follows the parameters of reliability for use in humans, which is already validated in the literature (Liao et al., 2014; Stillman, 1970). It consists of remote control, power cord, and vibration cells distributed throughout the blanket, which is 72 cm high and 52 cm wide. The vibration intensity can be adjusted to the minimum level of 1 and a maximum of 8 corresponding to frequency of 35 Hz to 80 Hz, according to the comfort of each individual. Based on the literature and studies that corroborate the reliability and validity of the parameters used in this study, we used vibratory stimuli with low intensity (sine oscillations < 1 g), frequency of 40 Hz and amplitude of 1.8 mm for the application of this treatment protocol (Kim et al., 2015; Rauch et al., 2010; Silva et al., 2011).

Initially, the experimental protocol consisted of volunteer in the supine position with the ipsilateral limb surrounded by the vibration blanket, supporting it elevated. The volunteer was subjected to 15 minutes of continuous vibration (Silva et al., 2011) with a frequency of 40 Hz and intensity respecting her tolerance.

The frequency of 40 Hz was selected to promote improvements in motor skills, through the increase in joint range, increased strength, and muscle fiber recruitment, to supply interneuron activities to the skin and receptors in the spinal cord, which reduce pain signals across C nerve fibers and increase the metabolic rate and blood flow (Kim et al., 2015; Yang and Seo, 2015).

Statistical analysis

Descriptive and parametric statistical analyses were performed using the BioEstat® 5.3 software version (BioEstat, 2015 considering all variables from the EMG capture and the dynamometry test presented a normal distribution according to the D'Agostino normality test. All the graphs were plotted using OriginPro Version 8 software (OriginLab…, 2015).

To verify the existence of statistical differences between the means of the data, we used the ANOVA test analysis, two parallel samples, considering the following conditions: CG (electromyography and dynamometry) and VTG before and after treatment as well as 3 months after the termination of treatment. In this study, the significance level for each comparison defined as statistically significant value $p \leq 0.05$.

Results

A statistically significance level was evident when we compared the minimization of pain intensity before and after the experimental protocol in the VTG ($p < 0.0001$), and when we compared initial treatment with reassessment after 3 months ($p < 0.0001$), which shows the long-term effects of vibration therapy, represented by Figure 1. The assessment after treatment compared to 3 months later found significant increased pain intensity ($p < 0.0001$). However, even 3 months later the pain intensity of the VTG was lower than at the initial assessment.

Table 1 shows the results of the goniometer. It was possible to observe significant increase in range of motion of shoulder extension, horizontal abduction and adduction after the physiotherapeutic treatment. Whereas, the increase in range of motion of shoulder extension and flexion remained three months after treatment, while horizontal abduction and adduction movements decreased significantly.

Figure 2 represents the values for the electromyographic activity of biceps (A), triceps brachial (B), deltoid (middle fibers) (C), and upper trapezius (D) muscles during shoulder flexion movement of both groups, VTG and CG.

When comparing the CG with VTG before treatment, it was possible to observe that the myoelectric activity of deltoid muscle fibers had higher RMS signal ($p = 0.0013$). However, the upper trapezius muscle had lower RMS signal ($p = 0.0032$) in the VTG. Comparing CG with VTG after treatment showed an increase in electrical activity of the biceps muscles and middle deltoid, but no significant values. At 3 months after the end of treatment, VTG triceps muscle had increased electrical activity when compared to the CG ($p = 0.0019$).

After treatment, the VTG had a significant increase in the RMS signal of the upper trapezius muscle ($p = 0.0164$), no significant increase in the triceps electrical activity, as well as decreased

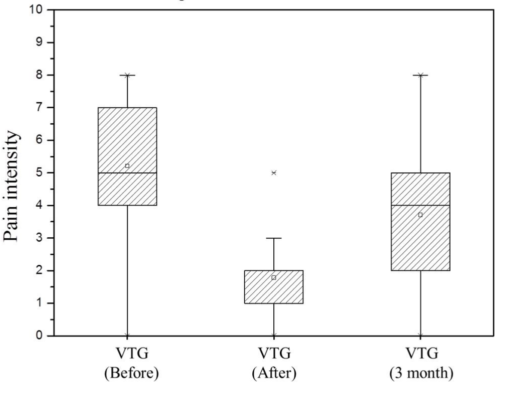

Figure 1. Box plots of the mean and two standard errors of the pain numerical scale related to vibration therapy group (VTG), comparison of before, after, and three months after the end of treatment.

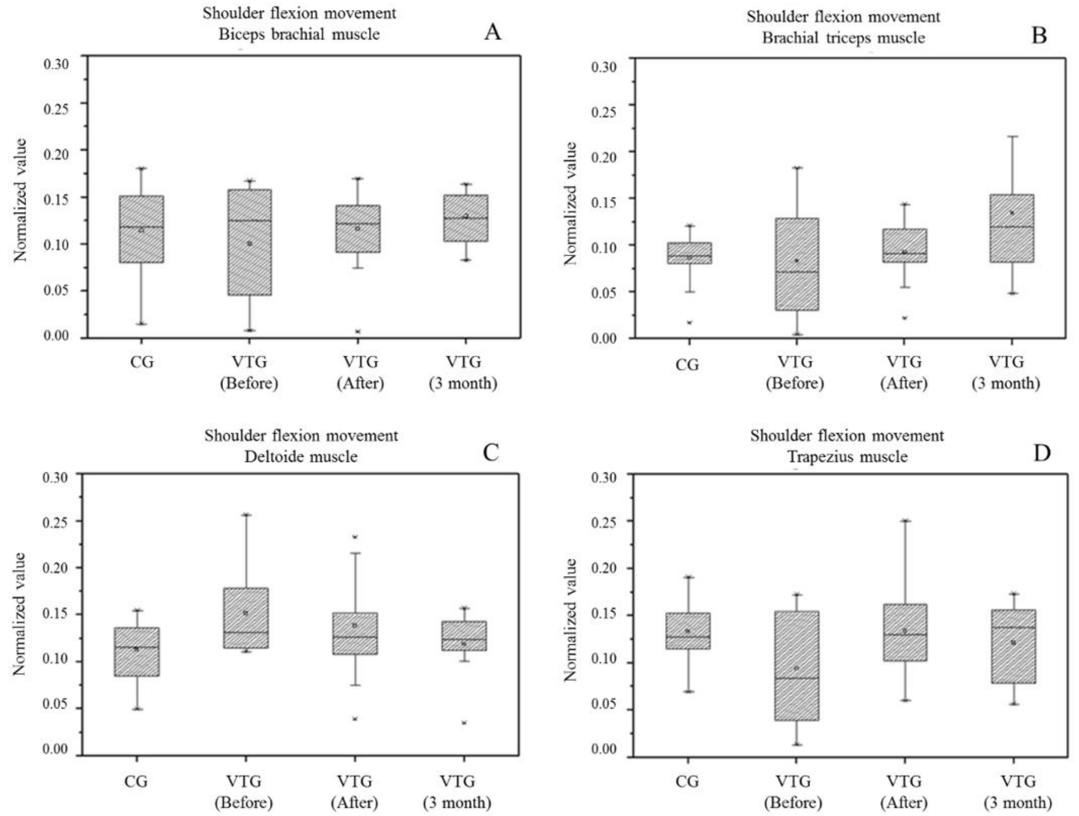

Figure 2. Box plots of the mean and two standard errors of the RMS values of the RMS values from myoelectric signal during shoulder flexion movement of control group (CG) and vibration therapy group (VTG). (A) Biceps muscle; (B) Triceps muscle; (C) Deltoid muscle; (D) Trapezius muscle.

Table 1. Results obtained for range of motion measured by goniometry.

Movement	Media ± standard deviation			p		
	Before	After	3 months	Before vs after	Before vs 3 months	After vs 3 months
Flexion	135.7 ± 9.3	142 ± 9.6	143.5 ± 13.3	ns	ns	ns
Extension	33.2 ± 11.3	47.9 ± 11.8	44.2 ± 10.1	< 0.0001*	0.0008*	ns
Abduction	124.6 ± 20	156.0 ± 18.8	134.2 ± 29.2	< 0.0001*	ns	0.0002*
Horizontal adduction	24.2 ± 6.4	28.5 ± 6.6	17.8 ± 6.9	0.0317*	< 0.0001*	< 0.0001*

*Anova ($p \leq 0.05$); ns: not significant.

electromyographic activity of the middle deltoid, when compared with the CG. However, it was not possible to notice any significant changes in biceps.

Relative to VTG assessments before experimental protocol and 3 months later, the volunteers maintained some long-term results, with increased RMS signal of triceps (p = 0.0099) and decreased RMS signal of deltoid (p = 0.0006). The electromyographic activity of the upper trapezius muscle fibers reduced 3 months after the second assessment, but remained higher than the signal before experimental protocol. The result of triceps showed significant differences (p = 0.0255) after treatment assessment compared to three months later.

Figure 3 represents the values for the electromyographic activity of biceps muscle (A), triceps brachial (B), middle deltoid (C), and upper trapezius (D) during the shoulder abduction motion of VTG and CG.

When we compared the VTG before treatment with the GC during shoulder abduction movement, note that women after breast cancer had lower myoelectrical activity of muscles analyzed, but with significant results only for the trapezoidal upper fibers

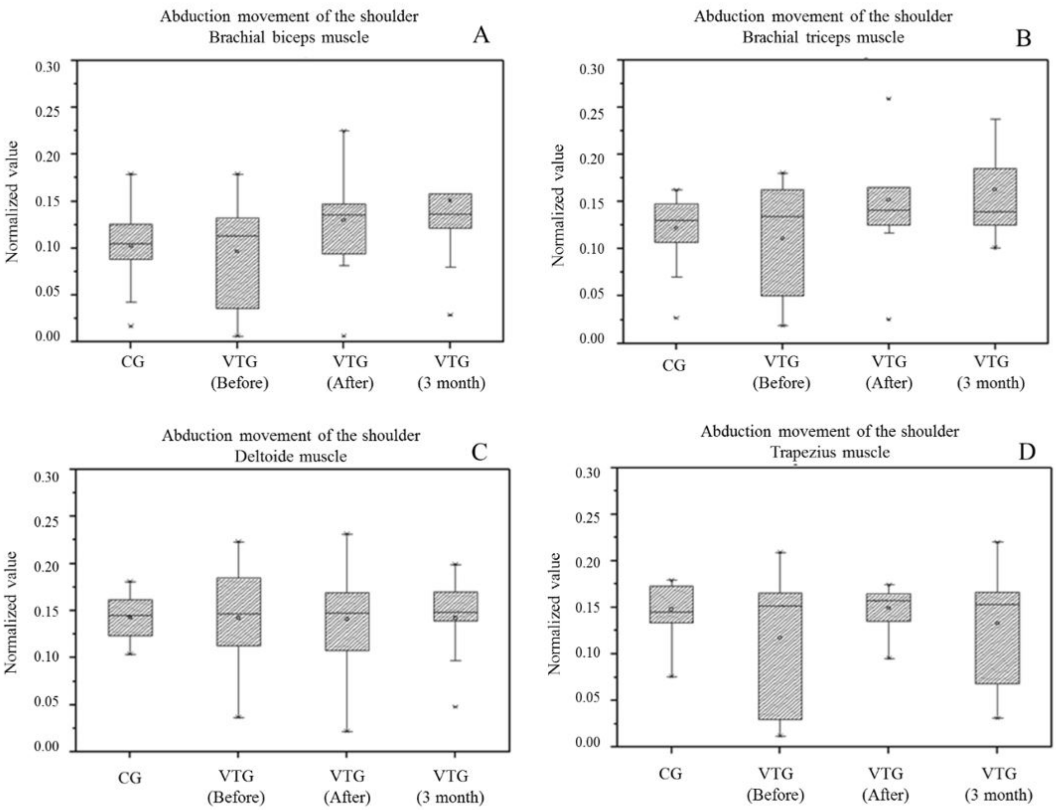

Figure 3. Box plots of the mean and two standard errors of the RMS values of the RMS values from myoelectric signal during shoulder abduction movement of control group (CG) and vibration therapy group (VTG). (A) Biceps muscle; (B) Triceps muscle; (C) Deltoid muscle; (D) Trapezius muscle.

(P = 0.0340). Soon after treatment, these women showed a significant increase in the recruitment of muscle fibers of biceps (p = 0.0213) and triceps (p = 0.0290) compared with healthy volunteers, and this remained three months later.

The VTG showed that after the experimental protocol and 3 months later, there was a significant increase in RMS signal of biceps (p = 0.0071) and triceps (p = 0.0017). The upper trapezius muscle showed no significant increase in myoelectrical activity compared with the initial assessment. Deltoid medium fiber muscle had no signal change.

It was not possible to observe significant RMS values for VTG after treatment compared with three months later, but an increased myoelectric activity of the biceps along with the decreased signal of trapezius upper fibers were noticeable. In addition, triceps and deltoid muscles kept the average signal values obtained after experimental protocol.

Data regarding to shoulder dynamometry, presented in Figure 4, were statistically significant, showing less muscle strength in after breast cancer patients than in the control group, in all situations: before (p < 0.0001), after treatment (p = 0.0024), and 3 months after treatment (p = 0.0008).

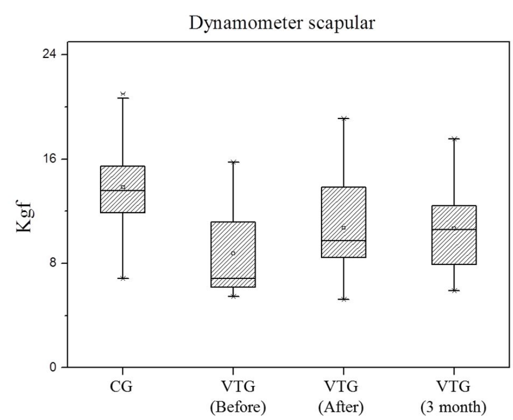

Figure 4. Box plots of the mean and two standard errors of the values from shoulder dynamometry of control group (CG) compared to vibration therapy group (VTG).

The intra-group analysis of VTG showed increased muscle strength after treatment (p = 0.0005) compared to initial assessment, as well as before compared to three months after (p = 0.0006). There was no significant difference after treatment compared to three months later, but the gained muscle strength remained.

Discussion

This study describes the alterations that can influence the biomechanics of the shoulder joint of post-surgical breast cancer women. Usually these women have the clinical condition of pain, reduced range of motion and muscle function (Haddad et al., 2013). This study proposed the use of vibration as a therapeutic resource in order to minimize these symptoms.

Vibration is a non-pharmacological therapeutic technique used to alleviate pain by the activation of superficial and deep mechanical receptors. The vibratory stimuli are transmitted by the Meissner corpuscle, which is sensitive to about 40 Hz and by Vater-up Paccini corpuscle above 100 Hz (Rittweger et al., 2010).

In this study, we found that vibration therapy was effective to minimize the intensity of pain in post-surgical breast cancer women, after ten 15-minutes sessions of experimental protocol. This finding corroborates the study of Volz et al. (2013), which reported 70% reduction of chronic and acute pain after vibration therapy. They concluded that vibration stimulus increases neuronal conduction of signals, through the large diameter myelinated fibers, and inhibits short fibers of spinal dorsal horn before the synapse. This hypothesis may be associated with the reduction of pain perception, in which the superficial receptors interact with deep receptors in spinal cord synaptic transmission and in nociceptive processing, which decreases the pain threshold.

Nevertheless, Dahlin et al. (2006) applied vibration in healthy women for twenty minutes and said that this time was sufficient to promote pain relief. Other studies have reported that the appropriate application time is still unknown, contradicting the time stated by the author above (Mikhael et al., 2010; Osawa et al., 2013).

On reevaluation after three months, increased pain intensity was observed, when compared to the end of treatment (10 sessions); however, this increase was less intense than measured initially at the first session. This finding corroborates with Bensmaia et al. (2005), which stated that the awareness of the nerve fibers are reversible with time.

Another common complication relative to breast cancer is the reduced range of motion of the shoulder (Galiano-Castillo et al., 2013). Smoot et al. (2010) stated that the deficit in the range of motion for post-treatment of breast cancer results from the formation of a scar tissue, radiation-induced fibrosis, antalgic posture of shoulder, disuse, and pain. These limitations interfere directly in daily-life activities, as difficulties in washing and combing their hair, for example. Early interventions are necessary in order to minimize these kinds of complications.

Some women report sensation of heaviness in the upper limbs due to the development of lymphedema and limited range of motion, which can result in severe pain, bursitis, tendonitis, or chronic injury with rotator ischemia and cuff. According to Jeong et al. (2011), the muscles that make up the rotator cuff are responsible for stabilizing the shoulder joint complex; however, tendinitis of the rotator cuff can be a complication related to lymphoedema, which is caused by internal derangement of the tendon fibers, generating functional overload.

Adriaenssens et al. (2012) conducted a randomized study with 119 women post-breast cancer in order to evaluate the morbidity of ipsilateral surgery shoulder. They observed that in the period of 1-3 months after radiotherapy, the upper limb volume increased 4.1%, and the movement of abduction decreased 8.6%. The authors stated that the compensatory muscle activity is necessary to improve the stability of the shoulder joint, which is associated with pain and muscle spasms. In this study, we observed a significant increase in range of motion of extension, abduction, and horizontal shoulder adduction movements, after the experimental vibration protocol. The gain was maintained in Post-surgical breast cancer women (VTG) three months after completion of treatment.

According to Martínez et al. (2013), vibration has beneficial effects on proprioception mechanisms and can influence the muscle cycles of contraction and relaxation, which can be detected by surface electromyography. This improvement is attributed to the tonic vibration reflex triggered by excitation of the muscle spindles.

The control group in this study included healthy women who participated only for assessing the myoelectric activity and muscle strength, so that these values could be a reference to compare with post-breast cancer women.

The post-breast cancer women (VTG) had reduced RMS signal obtained by electromyography compared to healthy women (CG), probably due to differences in muscle activation mechanism, as well as decreased muscle strength. However, after the vibration therapy, we observed the increase in RMS signal for the biceps, triceps, and deltoids muscles, as well as increased muscle strength, near the normal parameters.

Pereira et al. (2009) described the myoelectric activity of the muscles of the shoulder girdle after surgical treatment of breast cancer. The authors stated that the increase causes recruitment of muscle fibers in the scapular stabilization of the trapezius muscle, and the increase occurs due to deficits of other musculatures and the serratus anterior muscle. They found increased RMS value of the trapezius muscle due to a compensatory form for scapular stabilization; and increased electrical activity of the deltoid muscle as a strategy to keep the glenoid cavity of the humerus in a favorable position, as well as contribute to the complex stability of the shoulder during the execution of movements.

According to Foti et al. (2012), vibratory stimuli are responsible for activating spindle receivers that innervate the agonist and antagonist muscles when both work synchronously. Vibration stimuli increase neurons firing and, subsequently, increase the excitability of muscle spindles and muscle strength.

Based on the reported results, we found that vibration therapy could improve the musculoskeletal function, because the vibratory stimuli generate increased firing of neurons, and subsequently increase excitability of muscle spindles, which leads to an increase in recruitment of muscle fibers, providing improved muscular strength, increased range of motion and attenuation of the painful condition of post-surgical breast cancer women. Therefore, we suggest the inclusion of the vibration blanket proposed in this study as a therapeutic device, which may assist in reducing the morbidity after breast cancer.

In the course of this study, points were identified to be developed in future studies, which corroborate with the results described, among them are: the application of this therapeutic resource with a larger sample number and long-term treatment with vibration therapy for post-breast cancer complications.

Vibration therapy attenuated pain symptoms, improved joint movements of the shoulder, muscle activation mechanisms, and strength of post-surgical breast cancer women, as well as assisted in the long-term relief of symptoms. Therefore, vibration blanket may be considered a beneficial therapeutic resource to be inserted in rehabilitation programs of post-surgical breast cancer patients.

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