ORIGINAL ARTICLE

Robotic rehabilitation in clinical complications after breast cancer: exoskeleton of upper limbs

Reabilitação robótica nas complicações clínicas após câncer de mama: exoesqueleto de membros superiores

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ABSTRACT

Background: Breast cancer promotes several physical and functional changes. Innovative techniques of physiotherapeutic treatment, such as robotic rehabilitation may contribute to the prevention or treatment of these complications. Here we aim to evaluate the effects of robotic rehabilitation on clinical complications secondary to breast cancer. Methods: This is a longitudinal clinical study consisting of 26 subjects divided into the following groups: 13 patients (women after breast cancer - G1, Robotic Rehabilitation Group) and 13 healthy women who did not undergo surgery due to breast cancer and constituted the GC (Control Group) to obtain data from electromyography and dynamometry. Ten consecutive therapeutic sessions were performed. The following parameters were evaluated in three sessions (session 1 - S1, session 5 - S5 and session 10 - S10): scapular and manual force, myoelectric activity, pain, range of motion, lymphedema and quality of life. Results: Pain threshold attenuation was obtained by comparing S5 with S10 ($p = 0.002$) and at the end of treatment ($p = 0.01$); lymphedema reduction after 10 sessions ($p = 0.04$); increase of abduction ROM when comparing S1 with S10 ($p = 0.05$); flexion ($p = 0.002$) in S1 in relation to S10 and shoulder extension ($p = 0.05$) in S5. Regarding the electromyographic analysis, there were increases in scapular and manual force of the GC versus G1, and changes in variables estimated from the collected signals, especially the increase in signal amplitude for the MAV, PEAK and RMS characteristics of the brachial biceps muscles, anterior and middle deltoid when comparing S1 versus S10. Before the evaluation using the dynamometer, the healthy women presented increase of scapular and manual force in relation to the volunteers after breast cancer. Conclusion: The use of robotic therapy was significantly efficient for pain attenuation, lymphedema, increase range of motion, increased recruitment of muscle fibers and improvement of muscle synergism, which contributed to the improvement of the quality of life.

Keywords: Breast cancer, Exoskeleton Device, Electromyography, Pain, Range of motion.

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RESUMO

Introdução: O câncer de mama promove diversas alterações físico-funcionais. As técnicas inovadoras de tratamento fisioterapêutico, como a reabilitação robótica podem contribuir na prevenção ou tratamento dessas complicações. **Objetivos:** avaliar os efeitos da reabilitação robótica nas complicações clínicas secundárias ao câncer de mama. **Metodologia:** Trata-se de um estudo clínico longitudinal constituído por 13 mulheres após câncer de mama, G1 (Grupo reabilitação robótica) e 13 mulheres que não realizaram cirurgia devido câncer de mama, e constituíram o GC (Grupo Controle) para obtenção dos dados de referência de eletromiografia e dinamometria. Foram realizados dez atendimentos clínicos consecutivos. Na sessão 1 (S1), sessão 5 (S5) e sessão 10 (S10) foram avaliados os seguintes parâmetros: força escapular e manual, atividade mioelétrica, dor, amplitude de movimento, linfedema e qualidade de vida. **Resultados:** Foi obtida atenuação do limiar de dor ao comparar S5 com a S10 (p=0,002) e ao término do tratamento (p=0,01); redução do linfedema após 10 sessões (p=0,04); aumento da ADM de abdução ao comparar S1 com S10 (p=0,05); flexão (p=0,002) na S1 em relação S10 e extensão de ombro (p=0,05) na S5; e melhora da qualidade de vida nos domínios D, EGS, V, AS e SM. Em relação a análise eletromiográfica observou-se aumento da força escapular e manual do GC versus G1, e alterações em variáveis estimadas a partir dos sinais coletados, destacando-se o aumento na amplitude do sinal para as características MAV, PEAK e RMS dos músculos bíceps braquial, deltóide anterior e médio ao comparar S1 versus S10. Diante da avaliação utilizando o dinamômetro, as mulheres sadias apresentaram aumento da força escapular e manual em relação as voluntárias após câncer de mama. **Conclusão:** o uso da terapia robótica foi positivo para a atenuação da dor, linfedema, amplitude de movimento, aumento no recrutamento de fibras musculares e melhora do sinergismo muscular, fatores estes que contribuíram na melhora do questionário de qualidade de vida.

Palavras chave: Câncer de mama, Reabilitação robótica, Eletromiografia, Dor, Amplitude de movimento.

Background

According to the National Cancer Institute José Alencar Gomes da Silva (INCA), in 2023/2025 there are an estimated 73 million new cases of breast cancer in Brazil, responsible for the illness and death of the population in the world, with a prevalence of 66.54 new cases every 100 thousand women[1,2].

The surgical approach to breast cancer has evolved substantially over the past few decades. Mastectomy remains an important option; however, in the early stage of breast cancer, conservative surgery followed by radiotherapy still the most used choice in Brazil, with acceptable rates of local recurrence, survival, and aesthetic outcomes. Both surgical techniques involve the dissection of axillary lymph nodes, common sites of mammary carcinoma metastasis[3,4].

The clinical complications resulting from the surgical treatment of breast cancer, regardless of the modality adopted, associated with axillary dissection, can reach 70% of the patients, and mainly include pain, lymphedema, sensory and motor dysfunction of the shoulder, which has a considerable impact on short and long term on the quality of life of women[5].

Some symptoms are common after breast cancer surgery, such as disuse, pain, paresthesia and decreased strength, which begin within a few days after surgery and tend to increase over time, leading to decreased range of motion (ROM) and motor function of the shoulder. According to the literature, in the second week after surgery, 40% of the patients presented reduction of the abduction movement of the shoulder, 37% presented reduction of the flexion movement and 17% to 33% decreased muscle strength[6,7].

In addition, pain post mastectomy syndrome is defined as chronic neuropathic pain after any type of breast surgery. The pain intensity is in general moderate with neuropathic features in the ipsilateral breast and upper limb lasting up to 6 months. This condition occurs due to nerve lesions during surgery and may generate compensatory alteration in muscle activation[8].

Early rehabilitation focuses on the prevention of complications such as lymphedema, retractions and shoulder dysfunctions, as well as encouraging the patient to resume her daily activities with physiotherapeutic interventions at all stages of cancer treatment through appropriate clinical evaluation[9].

Robotic technology has been gaining prominence in rehabilitation, increasingly used to treat motor deficits of the upper limbs with high intensity training. This training modality seems to be one of the determinants of motor recovery, producing positive results in relation to the motor control and the capacity to perform movements[10,11].

Robot-assisted rehabilitation or robotic rehabilitation is usually combined with virtual reality and developed with the purpose of assisting the patient in relearning the movements and daily activities. This innovative technology allows the patient to practice several tasks and increases motivation throughout the process[11].

However, due to the recent introduction of this therapeutic modality, further studies specially controlled clinical trials on the efficacy of robotic rehabilitation after breast cancer are needed. In this context, the purpose of the present study was to evaluate the effects of robotic rehabilitation on myoelectric activity, scapular and manual force, pain, range of motion, perimetry and quality of life of women submitted to breast cancer surgery.

METHOD

To study the efficacy of robotic rehabilitation after breast cancer surgery, we designed a blinded longitudinal clinical study. The study protocol includes two groups: robotic rehabilitation group (G1), consisting of thirteen post-breast cancer women with a mean age of 54.8 ± 10 years, and the control group (CG) by thirteen healthy middle-aged women of 48.6 ± 11 years.

The study protocol was approved by the Ethics and Research Committee (CEP) under the number CAAE 41887715.0.0000.5503 and in the Clinical Trials database under the number NCT03105440. It was carried out in the Laboratory of Sensory Motor Rehabilitation Engineering (LERSM) belonging to the Research and Development Institute (IP&D) of the University of Vale do Paraiba (UNIVAP). All the volunteers who participated in the study signed the Informed Consent Term.

Inclusion criteria included: women who underwent conservative or non-conservative surgical procedure for breast cancer and axillary lymphadenectomy; minimum of 10 days of surgery and maximum of 6 years; age group from 30 to 70 years; sedentary and those who agreed and signed the Informed Consent Term. Among the exclusion criteria, the following aspects were considered: women diagnosed with other types of carcinomas, or those with no medical referral.

Regarding the control group, we included women who did not undergo breast cancer surgery (healthy volunteers), with ages ranging from 30 to 70 years. The CG was not submitted to the physiotherapeutic treatment and was included as a reference to obtain data of surface electromyography and dynamometry, as a standard muscular behavior, scapular and manual force.

The personal and clinical data of the volunteers after breast cancer (G1 - Virtual Reality Group) were obtained in the physical therapy evaluation and data collection based on the evaluation of the myoelectric activity, muscular strength, pain intensity, range of motion, upper limb circumference and quality of life. In relation to the control group (CG) the personal data of the volunteers were obtained, and three data collections of electromyography and dynamometry were performed on alternate days.

G1 data collection was performed at three different times: before initiating treatment (session 1), ie after the physical therapy evaluation of the volunteer; by completing five sessions (session 5), and at the end of ten treatment sessions (session 10). After physiotherapeutic evaluation and allocation into experimental groups, the subjects performed the physical therapy protocol, as described below.

Physical Therapy Protocol

The volunteers underwent robotic rehabilitation through the Hocoma® brand Armeo®Spring exoskeleton, used for robot assisted functional training of the affected upper limb. The Armeo®Spring is an upper limb exoskeleton consisting of a superior arm module, a lower forearm module and a pressure sensitive grip. Each module of the equipment has the adjustable length to correctly align the exoskeleton to the joints of the limb to be treated.

Initially, the equipment was adjusted to the height of the volunteer, positioned in sedestation, allowing support against the action of the severity of the arm and forearm, supporting 45º of shoulder flexion, in order to facilitate the movement of the limb. Before the volunteer started the therapy with the virtual games, adjustments were made in the three-dimensional workspace in the equipment's own software, which are mapped in a 3D cubic space and calibrated individually according to the following parameters: left, right, top, background, pronation, supination and grip strength.

The functional exercises described below were added to the therapeutic plan according to the initial calibration and difficulty level, which were repeated twice, with an interval of approximately two minutes rest between each activity.

- Game 01 - Rain in the cup: lateral movements with the mug (left / right) to collect drops that fall randomly, performing elbow flexion-extension movements and adduction and abduction of the shoulder.

- Game 02 - Cleaning stove: movements in the horizontal plane to clean the entire surface of the stove using a sponge, performing elbow flexion-extension movements, adduction and shoulder abduction and grasping.

- Game 03 - Clean the window: movements in the horizontal plane to remove dust on the window with a sponge, with elbow flexion-extension movements, flexion, extension, adduction and abduction of the shoulder, pronation, supination and gripping

- Game 04 - Fish catch: catch the fish that are swimming inside the aquarium in the frontal plane, performing elbow flexion--extension movements, flexion, extension, adduction and abduction of the shoulder and gripping.

- Game 05 - Buy fruit: grab the large red apple and place it in the shopping cart by moving the arm in the front plane, with elbow flexion-extension movements, flexion, extension, adduction and abduction of the shoulder.

- Game 06 - Moorhuhun: Shoot against the maximum number of chickens to generate points, through elbow flexion--extension, flexion, extension, adduction and abduction of shoulder, pronation, supination and gripping movements.

- Game 07 - Vertical reach: pick up the ladybug by moving the hand in the vertical plane, which disappears and another appears in a new place, performing elbow flexion-extension, flexion, extension, adduction and shoulder abduction movements.

- Game 08 - Horizontal reach: reach the red ball by moving the hand in the horizontal plane, which when touched disappears and appears in another new place, performing the elbow flexion-extension, flexion, extension, adduction and shoulder abduction movements.

Evaluation tools

Surface electromyography: The myoelectric signal was acquired by an electromyographic EMG System do Brasil Ltda., Model EMG830 WF of eight channels, composed by an A / D converter (analog-digital converter) of 16 bits of resolution. The signals were sampled at a rate of 2,000 Hz.

For the acquisition of signals, reusable Ag / AgCl electrodes (silver / silver chloride) with plastic edge and metal center were used, in the form of a disk, active bipolar (preamplified) with size of ten millimeters and distance between the center of the electrode of twenty millimeters between them. The electrodes were coated with conductive gel and adhered to the skin, fixed with disposable adhesive discs after the hygiene of the area with 70% alcohol soaked cotton in order to minimize skin impedance.

The surface electrodes were positioned in pairs on the motor point of the brachial biceps, anterior deltoid, medial deltoid and upper trapezius muscles, according to the Surface-EMG protocol for the Non Invasive Assessment of Muscle (SENIAM)[12], following the longitudinal direction of the muscle fibers.

The reference electrode was positioned on the styloid process of the ulna on the contralateral side of the limb that underwent surgical intervention and EMG signals were collected during maximal isometric contraction, according to synchronization with the scapular dynamometry protocol.

Electromyography was performed in synchrony with the scapular dynamometer only, for correlation of the values of myoelectric activity and strength, as justified in the study by Akoochakian et al.[13] where the authors stated that manual tightening did not evaluate the complex muscles of the shoulder. Besides, the authors refers that manual dynamometry is a valuable resource for the accurate evaluation of the manual grip force, which is significantly affected after breast cancer.

Dynamometry: Force measurement was performed using the EMG System do Brasil dynamometer, DFE021115 / 200 scapular dynamometer model and manual dynamometer model NS_00719, connected to the electromyography and the computer network. The signals were sampled at a rate of 2,000 Hz.

Scapular dynamometry data were collected with the volunteer in a sitting position, with feet resting on the floor and shoulders in abduction of ninety degrees along with elbow flexion and both hands holding the equipment. From this position, guidelines were given to perform adduction movement of the shoulder blades for 20 uninterrupted seconds, performing maximum isometric force.

The data of manual dynamometry were collected with the volunteer in position of sitting, feet supported in the ground, with the shoulder and elbow slightly flexed, and neutral position of forearm and wrist. The volunteer was instructed to perform maximum isometric manual grasp force for 20 uninterrupted seconds.

The dynamometry and electromyography signals obtained were saved in .txt format and processed in MATLAB® R2015a software (Mathworks Inc., Natick, MA, USA), which were organized in a spreadsheet for further analysis.

Numerical pain scale: Measurement of pain intensity consisted of a horizontal numbered line, from 0 to 10, with the extremities indicating “absence of pain” and “worst possible pain”. The volunteers were instructed to classify the pain in notes within the existing value in the scale, according to the intensity of the sensation.

Goniometry: The range of motion (ROM) of the shoulder was measured using an ISP® goniometer made of transparent plastic with two 20 cm rulers and transferred from 0 ° to 360 ° (degrees), consisting of a fixed arm, and axis.

Measurements of the movements were performed with the volunteer standing, considering the movements of flexion, extension, horizontal adduction, and abduction of the ipsilateral side of the surgical procedure. The volunteers were previously instructed on the movements that should be performed in order to familiarize them with the test. The subjects performed the movements actively until they had finished the entire range of motion, from that angle the record was made.

Perimetry: the measurement of the circumference of the upper limbs was performed by means of an inelastic anthropometric tape, in which the volunteer was instructed to remain in the sitting position, with the limb to be evaluated naked in pronation.

The measurement of the circumference was performed in both upper limbs as measured at specific points of the arm (1° - Measurement between acromion and olecranon obtaining the central point, 2° - Midpoint between acromion and central point; between olecranon and central point) and forearm (4° - Measure between olecranon and styloid process of the radium obtaining the central point 5° - Mid point between olecranon and central point 6° - Midpoint between the styloid process and central point) .

Quality of life: Quality of life assessment began with the clear and objective explanation of the questionnaire for better understanding, followed by the therapist's application, allowing true answers from the participants, in a private and confidential setting.

The translation and validation of the questionnaire were performed by Ciconelli et al.[14] who described the questionnaire formed by 36 items grouped in 8 domains, described below:

1. Functional Capacity (FC) (ten items): evaluates the limitations related to physical capacity;

2. Limitations by Physical Aspects (LPA) (four items): assesses how much the limitations make difficult the activities of daily life and work;

3. Pain (P) (two items): evaluates the pain intensity and its influence on the activities of daily living;

4. General Health Status (GH) (five items): assesses how the patient feels about his / her overall health;

5. Vitality (V) (four items): evaluates the level of fatigue and energy;

6. Social Aspects (SA) (two items): evaluates the integration of the individual in social activities;

7. Emotional Aspects (EA) (three items): evaluates the well-being in relation to the psychological aspects;

8. Mental Health (MH) (five items): assesses psychological well-being, anxiety, depression, behavior and emotional unrest.

The questions were scored in accordance with pre-established standards, through specific calculations for each item, obtaining separately the value of the questions, whose scores range from 0 to 100 representing the worst and the best quality of life. The result was called a raw scale because the final value does not have any units in measure.

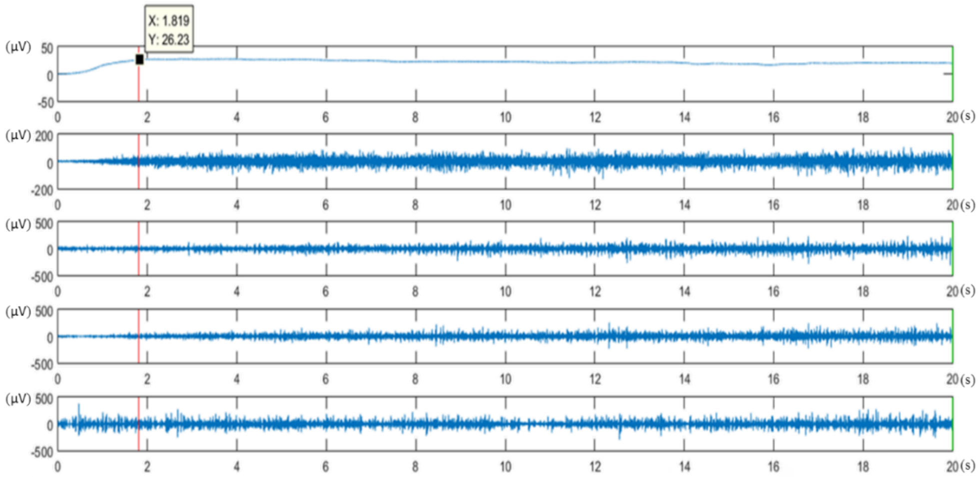
Obtaining each item of the questionnaire requires the application of the formula according to the study by Pimenta et al.[15] in which the lower limit value and the score range are fixed and stipulated.

Processing of biological signals

The signals obtained from surface electromyography and dynamometry were stored as a .txt file and processed in MATLAB® R2015a software (Mathworks Inc., Natick, MA, USA), in which a specific processing routine was created, which generated a graphical response for visualization and signal demarcation. After the spreadsheet was organized, the signal windowing process was performed, in which the muscle activity section was selected, executed in the MatLab® software, which generated the graphic representation of the signal for demarcation of the start time and end time of each channel of dynamometry and electromyography.

The synchronization of the dynamometry and electromyography signals allowed the demarcation according to force stabilization (channel 1 = dynamometry), used as a reference for the demarcation of electromyography signals (channels 2, 3, 4 and 5). Figure 1 illustrates the graphical visualization and demarcation of the start time (red line) and the final time (green line) of each channel. The values obtained for the start time and the final time were recorded in the aforementioned worksheet.

Figure 1: Graphical visualization and demarcation of the dynamometry and electromyography signals



After obtaining the spreadsheet with the data, the means of the signs that were fragmented were done, in order to leave a single value as reference. At the end of the organization of all signals, a second function, automatically executed by a set of specific routines to estimate the statistical values of the mathematical characteristics of the groups of amplitude, variability and frequency of the EMG signal.

- MAV: Mean Absolute Signal Value.

- PEAK: Estimates the maximum value of a vector.

- RMS: Root Mean Square.

- MAVSD: Average of the Absolute Value of the Second Difference.

- MAVFDN: Mean of the Absolute Value of the First Normalized Signal Difference.

- MAVFD: Average of the Absolute Value of the First Difference.

- MAVSDN: Mean of the Absolute Value of the Second Normalized Signal Difference.

- VAR: Variance.

- STD: Standard deviation of a series of signal values.

- RANGE: Interval; Estimate the difference between the maximum and minimum observed.

- INTERQ RANGE: Range Interval.

- ZC: Zero Crossing.

Numerous normalization methods of the electromyographic signals are currently used, among them we used the score, defined as a measure of dispersion that quantifies how much the data deviate from the standard deviation.

Statistical analysis

The Wilcoxon statistical test was applied through routine MatLab® software to obtain the statistical values of the mathematical characteristics of electromyography and dynamometry signals. The p values of each characteristic were obtained: MAV, PEAK, RMS, MAVSD, MAVFDN, MAVFD, MAVSDN, VAR, STD, RANGE, INTERQ RANGE and ZC.

The values obtained from the SF-36 quality of life questionnaire were scored according to the pre-established standards, as explained previously, which separately obtained the scores of each domain and, afterwards, the statistical test was applied.

After the organization of the spreadsheets referring to perimetry, numerical pain scale, goniometry and quality of life, the Wilcoxon statistical test was applied in BioEstat® software version 5.3 (Instituto Mamiraua, Manaus, AM), which is adequate to perform the following comparisons :

1) Comparison of EMG data and dynamometry of the control group (CG) in relation to the physiotherapy treatment sessions of G1.

2) Comparison of all variables analyzed between G1 physiotherapeutic treatment sessions (session 1 vs session 5 / session 5 vs session 10 / session 1 vs session 10).

The level of significance of each comparison was defined as statistically significant, $p \leq 0.05$. The data were presented in the form of tables and boxplot graphs.

RESULTS

The robotic rehabilitation group (G1) consisted of thirteen post-breast cancer women with a mean age of 54.8 ± 10 years, and the control group (CG) by thirteen healthy women with a mean age of 48.6 ± 11 years. Table 1 shows the demographic and clinical variables of the volunteers who participated in the study.

Table 1: Demographic and cancer-related variables of the volunteers in the study.

		G1		GC	
Demographic Data		**n**	**%**	**n**	**%**
Body Mass Index (BMI)	Normal Weight	4	30,8	2	15,3
	Pre-obesity	6	46,1	8	61,6
	Obesity	3	23,1	3	23,1
Civil State	Married	11	84,6	13	100
	Single	1	7,7	0	0
	Divorced	1	7,7	0	0
	Widow	0	0	0	0

School Level	Fundamental	6	46,2	1	7,7
	Middle	4	30,8	4	30,8
	University	3	23,2	8	61,5
Breast Cancer Related Variables					
Type of Surgery	Mastectomy	10	76,9	-	-
	Conservative Breast Surgery	3	23,1	-	-
Time after Surgery	41 – 60 days	13	100		
Removal of lymph nodes	Total	13	100	-	-
	Partial	0	0	-	-
Therapeutic Modalities	Radiotherapy only (R)	1	7,7	-	-
	Chemotherapy only (Q)	4	30,8	-	-
	R + Q	5	38,4	-	-
	None	3	23,1	-	-
Hormonal Therapy	Yes	1	7,7	-	-
	No	12	92,3	-	-

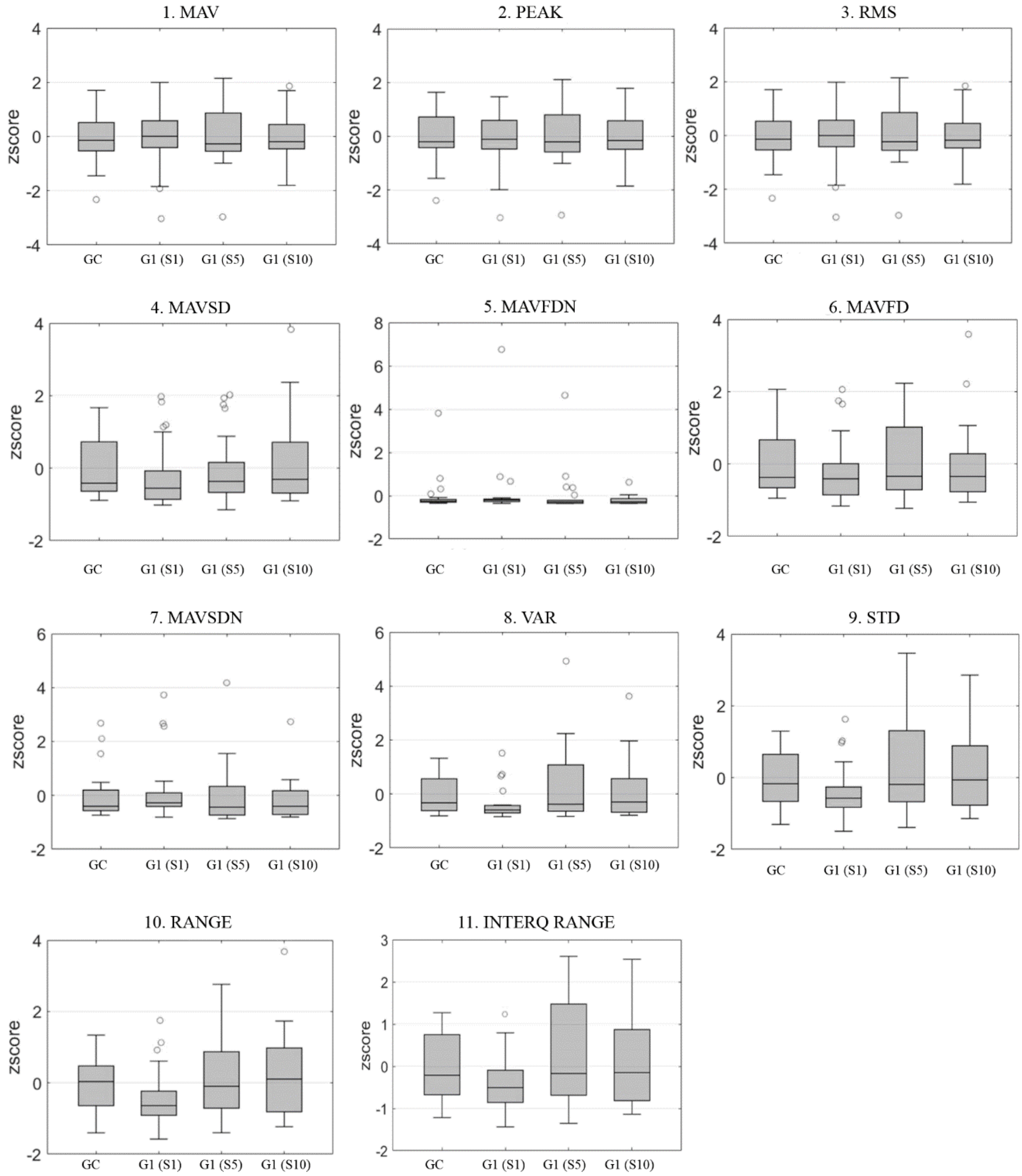
Figure 2 represents the characteristics extracted from the manual dynamometer signal of GC and G1. When comparing the CG in relation to the G1 (S1), it was possible to observe a significant increase for the MAVFDN characteristic (p = 0.01) and attenuation of the VAR (p = 0.003), STD (p = 0.006), RANGE (p = 0.02), INTERQ RANGE (p = 0.008). The MAVFDN characteristic (p = 0.02) showed an increase when compared with CG versus G1 (S10). However, the values were not significant when comparing CG with G1 (S5) of physiotherapeutic treatment.

When comparing G1 (S1) with G1 (S5), it was possible to observe a significant decrease for the MAVFDN characteristic (p = 0.03) and increase for VAR (p = 0.05), STD (p = 0.05) and RANGE (p = 0.04), however, the values were not statistically significant when comparing G1 (S5) with G1 (S10) (Figure 2).

There was a statistically significant decrease for the MAVFDN characteristic (p = 0.003), however, it was possible to note the increase for VAR (p = 0.008), STD (p = 0.06), RANGE (p = 0.008) and INTERQ RANGE (p = 0.01) when comparing G1 (S1) with respect to the end of G1 (S10) physiotherapeutic treatment (Figure 2).

Graphically, it was possible to observe attenuation of manual G1 strength in comparison to the control group, emphasizing the muscular strength deficiency after the surgical procedure of breast cancer (Figure 2).

Figure 2: Boxplot of the characteristics of manual dynamometry of the GC versus G1.

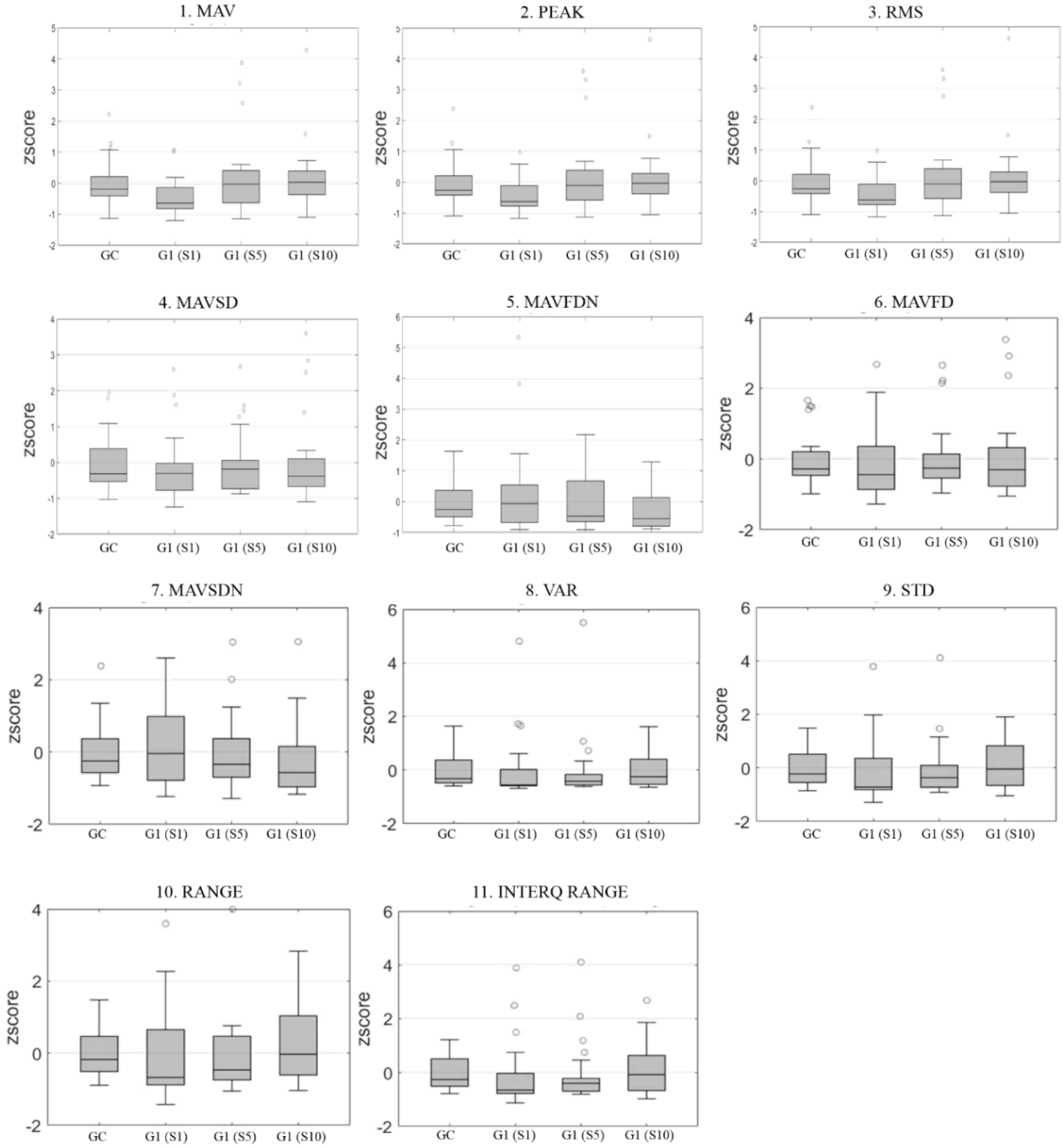


Legend: GC = control group; G1 (S1) = Virtual Reality Group before initiating treatment (session 1); G1 (S5) = Virtual Reality Group by completing five sessions (session 5); G1 (S10) = Virtual Reality Group complete of ten treatment sessions (session 10).

Figure 3 presents the characteristics extracted from the scapular dynamometry signal of GC and G1. Attenuation of scapular force was observed with significant values when comparing GC with G1 (S1) for the following characteristics: MAV ($p = 0.0007$), PEAK ($p = 0.001$) and RMS ($p = 0.0007$). However, there was a significant increase in GC scapular force versus G1 (S10) for the characteristics: MAV ($p = 0.01$), PEAK (p = 0, 01), RMS ($p = 0.01$), MAVFDN ($p = 0.01$), showing improvement in recruitment of muscle fibers after physiotherapeutic treatment.

Comparing the improvement of the physical therapy treatment of G1 (S1) with G1 (S5), it was possible to observe a significant increase in the characteristics: MAV ($p = 0.01$), PEAK ($p = 0.01$) and RMS ($p= 0.01$), however, the values were not significant when comparing S5 with respect to S10. Comparing the improvement of the physical therapy of G1 (S1) with the end of the physical therapy G1 (S10), it was possible to notice a statistically significant increase in the scapular force for the characteristics: MAV ($p = 0.0002$), PEAK ($p = 0.003$) and RMS ($p = 0.002$) (Figure 3).

Figure 3: Boxplot of the characteristics of scapular dynamometry of the GC versus G1.



Legend: GC = control group; G1 (S1) = Virtual Reality Group before initiating treatment (session 1); G1 (S5) = Virtual Reality Group by completing five sessions (session 5); G1 (S10) = Virtual Reality Group complete of ten treatment sessions (session 10).

Table 2 represents the statistical values obtained from surface electromyography of the control group (CG) in comparison to the treatment sessions of the robotic reality rehabilitation group (G1), and Table 3 represents the values obtained between the treatment sessions of the G1.

Table 2: Wilcoxon statistical test values of the CG compared to the G1 of the electromyography signals.

	Brachial biceps			**Anterior deltoid**			**Medial deltoid**			**Upper trapezius**		
	GCvsS1	GCvsS5	GCvsS10	GCvsS1	GCvsS5	GCvsS10	GCvsS1	GCvsS5	GCvsS10	GCvsS1	GCvsS5	GCvs10
MAV	↓0.006*	↑0.89	↑0.04*	↓0.03*	↓0.06	↓0.33	↓0.09	↓0.54	↓0.41	=0.73	↓0.24	↑0.41
PEAK	↓0.03*	=0.89	=0.41	↓0.01*	↓0.03*	↓0.08	↓0.09	↓0.27	↓0.73	↑0.89	↓0.33	↑0.45
RMS	↓0.004*	=0.78	↑0.04*	↓0.03*	↓0.06	↓0.27	↓0.09	=0.49	↓0.37	=0.73	↓0.24	↑0.41
MAVSD	↓0.004*	=0.78	↑0.03*	↓0.03*	↓0.05*	↓0.33	↓0.10	↓0.33	↓0.19	↑0.94	↓0.30	↑0.37
MAVFDN	↑0.89	↓0.94	↑0.03*	=0.27	↑0.04*	↑0.78	=0.49	↑1.00	=0.08	↓1.00	=0.73	=0.10
MAVFD	↓0.01*	=1.00	↑0.10	↓0.03*	↓0.05*	↓0.37	↓0.10	↓0.33	↓0.19	↑1.00	↓0.30	↑0.37
MAVSDN	↑0.78	↑0.94	↓0.10	↑1.00	↓0.49	↑0.94	↑0.68	↑0.78	↑0.06	↓0.63	↓0.49	↓0.30
VAR	↓0.001*	=0.73	↑0.04*	↓0.03*	↓0.08	↓0.21	↓0.03*	↓0.89	↓0.63	=0.78	↓0.24	↑0.83
STD	↓0.004*	=0.78	↑ 0.04*	↓0.03*	↓0.06	↓0.27	↓0.09	=0.49	↓0.37	=0.68	↓0.27	↑0.41
RANGE	↓0.04*	=0.78	↑0.24	↓0.03*	↓0.04*	↓0.21	↓0.06	↓0.54	↓0.33	=1.00	↓0.19	↑0.24
INTERQ RANGE	↓0.01*	=0.83	↑0.05*	↓0.03*	↓0.08	↓0.37	↓0.10	↓0.63	↓0.37	=0.63	↓0.33	↑0.49
ZC	=0.94	↓0.83	↓0.83	↓0.49	↓0.24	↑0.78	↓0.73	↓0.49	↓0.16	=0.49	↓0.94	↓0.33

Legend: (↑) baseline - signal increase; (↓) baseline - signal decrease; (=) without change; (*) significant p-value; S1 - session 1; S5 - session 5; S10 - session 10.

	Brachial biceps			Anterior deltoid			Medial deltoid			Upper trapezius		
	S1vsS10	S1vsS5	S5vsS10	S1vsS10	S1vsS5	S5vsS10	S1vsS10	S1vsS5	S5vsS10	S1vsS10	S1vsS5	S5vsS10
MAV	↑0,002*	↑0,07	↑0,12	↑0,03*	↑0,001*	↓0,33	↑0,07	↑0,23	↓0,50	↓0,36	↓0,12	↑0,52
PEAK	↑0,019*	↑0,22	=0,09	↓0,02*	↑0,006*	↓0,37	↑0,16	↑0,83	↑0,33	↑0,67	↓0,71	↑0,50
RMS	↑0,003*	↑0,09	=0,11	↑0,02*	↑0,001*	↓0,34	↑0,05*	↑0,22	=0,54	↓0,41	↓0,13	↑0,52
MAVSD	↑0,010*	↑0,11	=0,10	↑0,01*	↑0,0007*	↓0,31	↑0,04*	↑0,12	↓0,62	↑0,28	↓0,83	↑0,20
MAVFDN	↓0,007*	↓0,23	=0,06	↓0,02*	↓0,02*	=0,78	↓0,02*	=0,21	=0,26	=0,33	=0,67	=0,06
MAVFD	↑0,01*	↑0,12	=0,21	↑0,01*	↑0,0007*	=0,34	↑0,04*	↑0,12	↓0,62	↑0,23	↓0,78	↑0,17
MAVSDN	↓0,76	↓0,64	=0,80	↑0,62	↓0,17	↑0,62	↓0,50	↓0,83	↑0,36	↑0,78	↓0,41	↓0,18
VAR	↓0,003*	=0,10	=0,12	↑0,02*	↑0,001*	↓0,31	↑0,07	↑0,30	=0,58	=0,58	↑0,48	↑0,15
STD	↑0,003*	↑0,09	↑0,11	↑0,02*	↑0,001*	↓0,31	↑0,05*	↑0,22	=0,54	=0,42	↓0,60	↑0,11
RANGE	↑0,01*	↑0,31	=0,08	↓0,06	↑0,005*	↓0,50	↑0,10	↑0,31	↑0,46	↑0,54	↓0,73	↑0,12
INTERQ RANGE	↑0,003*	↑0,06	↑0,12	↑003*	↑0,016*	↓0,71	↑0,10	↑0,31	=0,46	↑0,36	↓0,50	↑0,07
ZC	↓0,15	↓0,18	↑0,92	↓0,07	↓0,028*	↑0,27	´=0,12	↓0,16	↑0,83	=0,78	↓0,42	↑0,67

Table 3: Values obtained from the Wilcoxon statistical test of the G1 of the electromyography signals.

Legend: (↑) baseline - signal increase; (↓) baseline - signal decrease; (=) without change; (*) significant p-value; S1 - session 1; S5 - session 5; S10 - session 10.

In the characteristics extracted from the brachial biceps muscle signal when comparing the CG in relation to G1 (S1), statistically significant values were obtained regarding the decrease in electromyographic activity for the characteristics: MAV ($p = 0.01$), PEAK ($p = 0.03$), MAVFD ($p = 0.01$), VAR ($p = 0.007$), STD ($p = 0.01$), RANGE ($p = 0.03$) e INTERQ RANGE ($p = 0.01$), however, the values of RMS ($p = 0.01$) and MAVSD ($p = 0.01$) remained unchanged visually. When comparing the GC with the G1 (S5) of physiotherapeutic treatment the values were not significant.

However, it was possible to observe an inversely proportional behavior when compared with the CG in relation to G1 (S10), in which the characteristics obtained increased with significant values: MAV ($p = 0.01$), RMS ($p = 0.01$), MAVSD ($p = 0.01$), MAVFDN ($p = 0.01$), MAVFD ($p = 0.04$), VAR ($p = 0.02$), STD ($p = 0.01$), RANGE ($p = 0.05$) and INTERQ RANGE ($p = 0.02$).

When comparing the G1, it was possible to observe a significant increase in the electromyographic activity of the brachial biceps at S1 in relation to S10 for the characteristics: MAV ($p = 0.002$), PEAK ($p = 0.01$), RMS ($p = 0.003$), MAVSD ($p = 0.01$), MAVFD ($p = 0.01$), STD ($p = 0.003$), RANGE ($p = 0.01$), INTERQ RANGE ($p = 0.003$), however attenuation in MAVFDN ($p = 0.007$) e VAR ($p = 0.003$). The values were not significant among the other comparisons.

Considering the features extracted from the anterior deltoid muscle signal, it was possible to observe attenuation of the electromyographic signal of the mathematical characteristics when comparing the GC in relation to G1 (S1) for MAV ($p = 0.001$), PEAK ($p = 0.004$), RMS ($p = 0.001$), MAVSD ($p = 0.001$), MAVFD ($p = 0.001$), VAR ($p = 0.001$), STD ($p = 0.001$), RANGE ($p = 0.005$) and INTERQ RANGE ($p = 0.007$).

When comparing GC with G1 (S5), it was possible to observe an inversely proportional behavior to that obtained previously, that is, a significant increase occurred for RMS (p = 0.05), MAVSD (p = 0.04), MAVFDN (p = 0.03), MAVFD (p = 0.05), STD (p = 0.04) and RANGE (p = 0.05). However, when comparing GC with session 10 of G1, the values were not significant.

Comparing the physiotherapeutic treatment sessions, a statistically significant increase was observed between G1 (S1) and G1 (S5) for the characteristics: MAV (p = 0.001), RMS (p = 0.001), MAVSD (p = 0.01), MAVFD (p = 0.0007), VAR (p = 0.001), STD (p = 0.001), RANGE (p = 0.005), INTERQ RANGE (p = 0.01), ZC (p = 0.02), but decreased for PEAK (p = 0.006) and MAVFDN (p = 0.02).

When comparing G1 (S5) with G1 (S10), the values were not statistically significant, however, it was possible to observe a significant increase when comparing G1 (S1) with G1 (S10) for the characteristics: MAV (p= 0.03), RMS (p = 0.02), MAVSD (p = 0.01), MAVFD (p = 0.01), VAR (p = 0.02), STD (p = 0.02), INTERQ RANGE (p = 0.03), and decrease for PEAK (p = 0.02) and MAVFDN (p = 0.02).

The characteristics of the medial deltoid muscle when comparing the GC with the G1 (S1) was obtained decrease in the variability of the signal for the VAR characteristic (p = 0.02), and when comparing GC with G1 (S10) in the amplitude for the MAVFDN characteristic (p = 0.05), however, in the other comparisons no statistically significant values were obtained.

In relation to the robotic rehabilitation sessions, there was a statistically significant increase only when comparing G1 (S1) and G1 (S10) for the following characteristics: RMS (p = 0.05), MAVSD (p = 0.04), MAVFD (p = 0.04), STD (p = 0.05), and decreased MAVFDN (p = 0.02).

In the upper trapezius muscle, it was possible to observe statistically significant attenuation in the characteristics: MAVFDN (p = 0.03) and MAVSDN (p = 0.05) when comparing the CG in relation to G1 (S10). However, no significant values were obtained in the other comparisons.

Regarding the results obtained between the G1 rehabilitation sessions, statistically significant values were not obtained for the upper trapezius muscle.

Attenuation of pain intensity was observed when comparing G1 (S1) to G1 (S5) (p = 0.36). The values were statistically significant in the following comparisons: G1 (S5) in relation to G1 (S10) (p = 0.02), and when comparing the session G1 (S1) versus G1 (S10) (p = 0.01).

G1 goniometry results showed increased range of motion of the shoulder after robotic rehabilitation. There was a statistically significant increase when comparing G1 (S1) to G1 (S5) (p = 0.05) for shoulder extension movement; G1 (S5) versus G1 (S10) (p = 0.02) for the shoulder flexion movement, and when comparing G1 (S1) versus G1 (S10) for shoulder abduction movement (p = 0.05).

Significant attenuation of the circumference of the affected upper limb was obtained by comparing G1 (S1) versus G1 (S10) (p = 0.04). There was a decrease, however, with non-significant values when comparing G1 (S1) versus G1 (S5) (p = 0.24), and G1 (S5) versus G1 (S10) (p = 0.34).

When comparing the healthy limb, no changes in limb circumference were obtained and the values were not statistically significant in the comparisons: G1 (S1) versus G1 (S5) (p = 0.24); G1 (S5) versus G1 (S10) (p = 0.39); and G1 (S1) compared to G1 (S10) (p = 0.77), suggesting that there was no accumulation of lymph in the contralateral limb.

Considering quality of life we could observe significant increases when comparing G1 (S1) versus G1 (S5) for the domains: Vitality (p = 0.04) and Social Aspects (p = 0.02). When comparing G1 (S5) with G1 (S10), there was a statistically significant increase for the domains: General Health Status (p = 0.04) and Mental Health (p = 0.05). In the comparison between G1 (S1) and G1 (S10) were obtained: Pain (p = 0.04), Vitality (p = 0.003), Social Aspects (p = 0.007) and Mental Health (p = 0.002).

DISCUSSION

In the present study, robotic rehabilitation was used as an innovative therapeutic resource for post-surgical recovery due to breast cancer. Robotic technology has been increasingly used to treat upper limb motor deficits with high intensity training. It is one of the determinants of motor recovery for producing favorable results in relation to motor control, and increasing the ability to perform activities of daily living and restoring the functionality of the upper limbs during the execution of repetitive tasks[16].

The repetition of the movement refers to the number of times that a specific behavior is performed. However, the specificity of the task seems to be quite relevant. Movement is planned in effector coordinates to reacquire a motor skill lost after damage. In this context, the focus should be on the final effector movements, for example: the hand and the fingertips, in which movement is produced by changing that effector from one position to another, rather than a programmed contraction of the individual muscles and joints. The planning and organization of the movement are important factors, since a movement is considered well executed if the trajectory presents smoothness temporal space with accurate and adequate velocity[17].

The robotic therapy used combines three basic components: (1) the mechanical component to which it is driven by active assisted movement of the hand to the target; (2) visual feedback on the computer screen, related to the performance of the requested tasks; (3) and an interactive computer program, which motivates the patient, monitors and progresses training[18].

In the present study, it was possible to observe a good adherence of the patients to the new therapeutic modality, which reported safety due to the aid of the robotic arm to perform the functional activities proposed by the software, and because it is a dynamic and motivating therapy, which generates a cognitive distraction in relation to the clinical complications after surgery.

According to Vigotsky et al.[19] surface electromyography is highly sensitive in the detection of depolarization and hyperpolarization that occur in the membrane of the muscle fiber. The motor unit consists of a motor neuron and the muscle fibers which converts the efferent action potential into force generation. There are two primary mechanisms by which the nervous system allows the production of muscle strength: recruitment of the motor unit and the coding rate, which plays an important role in modulating force.

Generally, after trauma, the muscles may be severely damaged or absent. Here we observed that post-breast cancer women had altered values of several parameters, showing differences in the mechanism of muscular activation, as well as scapular force and manual reduction in relation to healthy women, especially in the MAV, PEAK and RMS characteristics. In agreement to our findings, Monleon et al.[20] in a prospective longitudinal observational study evaluated the strength of the external rotators, internal and abductors of the shoulder by dynamometry, before surgery and at 1, 6 and 12 months after breast cancer surgery. The authors stated that muscle strength decreases significantly in the first month and does not recover to preoperative values in the first year of follow-up.

The amplitude characterizes how much the EMG signal varies in the Y axis, and are related to the contraction force of the muscles, ie, the larger the contraction force the greater the signal amplitude value[21].

The MAV feature calculates the average value of each absolute value of the samples in the window. The MAVFD is a point-to-point derivative of the MAV values, in order to evaluate the existence of a variation of the angular coefficient of the signal, and the MAVSD, represents the second derivative of these values. By means of the Peak it is possible to calculate the highest value reached by the amplitude within the window, emphasizing that only positive values are considered[21].

According to Zhang et al.[22] MAV is essential in determining the baseline EMG signal during daily movements and may be associated with other characteristics such as RMS and ZC.

The frequency of the signal represents how many times the signal repeats over time, in which the EMG signal consists of a summation of signals with frequencies varying in each time. This cycle is described when the signal leaves the point of rest, reaches the maximum value, decreases until reaching the minimum value and returns to its resting position[21].

The characteristic ZC, classified as frequency of the EMG signal, calculates how many times the wave crosses zero, going from a positive signal to a negative one and vice versa, that is, how many times the signal crosses line[23].

Adewuyi, Hargrove and Kuiken[24] stated that characteristics such as MAV and ZC are considered important in the classification of hand position in relation to the intrinsic musculature, that is, muscles that originate and are inserted in the hand itself. This condition presupposes that EMG characteristics are affected by changes in the extrinsic musculature in different positions, however, the intrinsic muscles, that is, those that do not cross the joint are less affected by the changes of position.

The commonly used dispersion measures are the interval, the interquartile range and the standard deviation. The interval is the difference between the largest and smallest signal observations. The interquartile range is defined as the difference between the first and third quartiles, so the interquartile range describes the means of 50% of the observations, in which if the interquartile range is large, it means that 50% of the observations are separated from each other. The advantage is that it can be used as a measure of variability if the extreme values are not being written correctly. The standard deviation is the measure of dissemination of the data over the mean, the most widely used measure of dispersion[25].

Sensory damage and pain can influence the performance of functional tasks, mainly due to the inhibitory effect of muscle[26].

According to Gonçalves et al.[27] the deltoid muscle presents greater activation at all angles of flexion of the arm compared to the upper trapezius muscle, related to the different muscular functions, since the main function of the anterior deltoid muscle is to stabilize the shoulder complex, in which the fibers anterior are main active for the flexion movement of the arm, and the function of the upper trapezius is to stabilize the humeral head and scapula.

In our study, it was possible to observe increased amplitude and variability characteristics of the anterior deltoid, middle deltoid and brachial biceps muscles at the end of the robotic rehabilitation protocol. This fact is justified by the increase in the recruitment of motor units, that is, an improvement in the contraction force of the muscles to perform the repetitive tasks, in which the volunteer needs to execute a movement with specificity, consequently promoting improved motor control.

Continuous activation of the upper trapezius and deltoid muscles is considered to be the main cause of pain or discomfort in the cervical region due to the stereotyped recruitment mechanisms of low threshold motor units, such as type I muscle fibers, associated with lack of time variation and spatial[27].

Haddad et al.[28] reported that there is a change in muscle contraction in the cervical and scapular region triggered by emotional stress, associated with muscle retraction caused by postoperative scarring or post-radiotherapy fibrosis. The grip strength also becomes diminished on the ipsilateral side of the surgical procedure as a result of lymphedema and secondary stiffness of the fingers.

Shamley, Lascurain-Aguirrebena and Oskrochi[29] stated in the results of a pilot study the association of deviations and alteration in the electromyographic activity of the key muscles of the scapuloumeral joint with pain and joint dysfunction. The authors observed increased muscle activity in all muscles assessed after mastectomy, which is justified by the reflex of the increased muscle activity that patients need to mobilize the shoulders, resulting in loss of tissue extensibility and scarring, in addition to being plausible this increase due to myogenic pain.

Shamley et al.[30] found that the retraction causes a decrease in the subacromial space, which allows the movement of the humeral head and the rotator cuff under the coracoacromial arch. Thus, they suggested that the changes in this space result in compression of the subacromial structures, such as bursa and rotator cuff during arm elevation, generating joint limitation and pain.

According to Díaz et al.[31] shoulder joint amplitude restriction is present in 21 to 30% of the women who underwent axillary lymph node dissection, and present common postoperative deficiencies, such as the subsequent effects of surgical healing and post-radiation induced fibrosis, which can disrupt the mechanics of the shoulder.

The authors also stated in the aforementioned study that, in addition to movement restriction, pain is a recurring symptom in this public. The intercostobrachial, cutaneous brachial nerves and intercostal nerves can be injured during surgery, or generate an acute postoperative inflammatory picture, causing sensory disturbance in the arm, breast and armpit, which may lead to increased neural mechanics and functional impairment. Another important finding was axillary nerve syndrome, a condition that occurs after axillary lymph node disruption, characterized as a dense, palpable and visible “cord” that extends from the axilla to the medial region of the affected arm, which is more prominent in the abduction movement of the shoulder. The axillary network syndrome varies from 28.1 to 48% of women, and develops between 1 and 5 weeks after surgery[32,33].

The hypothesis is that women with axillary nerve syndrome are less stimulated to mobilize the affected limb due to pain pictures, which leads to substantial atrophy due to muscle disuse, approximately at the level of the brachial biceps muscle[33].

The results showed that there was a significant increase in the range of motion and attenuation of the pain after the treatment using the exoskeleton, suggesting robotic rehabilitation as a therapeutic alternative for the treatment of joint limitations and pain after breast cancer surgery.

The positive effects of robotic rehabilitation on the improvement of range of motion and pain are associated with joint mobilization performed during game play, which stimulates peripheral mechanoreceptors and modulates nociceptors, allowing the exchange between the synovial fluid and the cartilage matrix, in addition to pain relief[32].

Wilson[5] emphasized the importance of an exercise therapeutic program in the postoperative period, including exercises that involve flexibility, stretching and mobilization of the shoulders, mainly for the prevention of adhesive capsulitis and tendinitis of the supraspinatus muscle and brachial biceps.

Scaffidi et al.[34] reported that patients who underwent an assisted-exercise program, started the first day after surgery, showed satisfactory improvements in joint amplitude of the shoulder, crucial for reducing the occurrence of side effects in the affected limb.

Evidence shows that the flow rate of the lymphatic fluid depends on the intermittent external pressure of the skeletal muscles, therefore, some authors emphasize that for the treatment and prevention of lymphedema, it is necessary to include the reactivation of the affected limb functions and to incorporate therapeutic exercises early[35].

In the study, robotic therapy proved to be effective in reducing lymphedema, probably due to the stimuli generated by the muscular contractions, which increase the venous-lymphatic return by pumping the lymph to the capillaries. However, it was observed that the healthy upper limb did not present alteration, suggesting that there was no lymphatic compensation, that is, lymph accumulation in the limb contralateral to the surgery.

Some authors have reported the pathophysiology of lymphedema based on the compensation and degeneration of lymphatic vessels. In the initial phase, the lymphatic vessels are dilated due to abnormally increased internal pressure. However, it is not clear from the literature whether lymphatic degeneration occurs gradually or abruptly[36].

According to Hansdorfer-Korzon et al[37]. after axillary lymphadenectomy, the contralateral side of the thorax is responsible for drainage of the lymph from the defective side. Therefore, it is assumed that lymphatic vessel lymphangiomotor activity will be compensated, which generates a slow in the normal transport of fluids and proteins.

Tang et al.[38] stated that early postoperative functional exercise due to breast cancer is safe and beneficial, and assists the patient in reducing ipsilateral adhesion, limb edema, joint stiffness, muscle atrophy, and limb function. Thus, the findings of the authors corroborated with the study in question, mainly in relation to the implementation of a program of functional exercises in the postoperative period, in order to attenuate the clinical complications in the long term.

The findings of the study also corroborate evidence from the literature regarding the decrease in quality of life after surgery due to breast cancer. According to Sharma and Purkayastha[39] the diagnosis of breast cancer negatively affects the woman's well-being, generating psychological and emotional disorders, sexual dysfunction and altered body image, which are influenced by frequently reported symptoms such as fatigue, insomnia, and ache.

In this study, the improvement in the quality of life of the volunteers in relation to functional capacity, pain, physical limitations, general health, vitality, social, emotional and mental health aspects was noticed.

Ahmed et al.[40] reported that patients with breast cancer had pain, poor physical function, poor vitality, and general poor health, according to the decrease in SF-36 scores. However, they noted that regular exercise was a positive predictor for overall health and emotional well-being.

Therefore, the patient's interaction with the proposed functional activities, and the execution of the exercise with the aid of the robotic arm, provided the patient with a dynamic, motivating and safe therapy, which contributed to the improvement of the shoulder, strength and function movements.

No related articles were found applicability of robotic rehabilitation for the treatment of acute clinical complications due to breast cancer. Since then, a new way of using this resource has been developed, which can help in minimizing post-cancer morbidity, one of the most complex physical rehabilitation programs.

Studies in the literature only report the weaknesses related to breast cancer, which makes the research pioneered in describing and treating these conditions with the use of new technologies.

CONCLUSION

Based on the results observed in this study, we conclude that the rehabilitation process is crucial in the treatment of acute clinical complications that are secondary to breast cancer.

In this context, it is extremely important to use biomedical equipment, such as surface electromyography and dynamometry associated with rehabilitation programs, as well as the development of technologies for biological signal analysis, providing an understanding of the responses and physiological adaptations that occurred during the use of different therapeutic modalities.

Our results regarding the robotic rehabilitation protocol showed beneficial effects in relation to pain relief and lymphedema in the affected limb, and improvement of the range of motion, mainly for shoulder abduction and flexion. Regarding electromyography and dynamometry, we concluded that there was an increase in recruitment of muscle fibers, increase of scapular and manual force. These factors contributed positively to obtaining good scores in the women's quality of life questionnaire.

List of abbreviations

Ag/Cl: Silver Chloride; Ag: Silver; CEP: Ethics and Research Committee; EA: Emotional Aspects; EMG: Electromyography; FC: functional capacity; GH: general health; INTERQ RANGE: Range Interval; IP&D: Research and Development Institute;

LERSM: Laboratory of Sensory Motor Rehabilitation Engineering; LPA: Limitations on physical aspects; MAV: Mean Absolute Signal Value; MAVFD: Average of the Absolute Value of the First Difference; MAVFDN: Mean of the Absolute Value of the First Normalized Signal Difference; MAVSD: Average of the Absolute Value of the Second Difference; MAVSDN: Mean of the Absolute Value of the Second Normalized Signal Difference; MH: Mental Health; P: Pain; PEAK: Estimates the maximum value of a vector; RANGE: Interval; Estimate the difference between the maximum and minimum observed; RMS: Root Mean Square; ROM: rang of motion; SA: Social Aspects; SENIAM: Surface-EMG protocol for the Non Invasive Assesment of Muscle; STD: Standard deviation of a series of signal values; TCLE: Informed Consent Term; UNIVAP: University of Vale do Paraiba; V: Vitality; VAR: Variance; ZC: Zero Crossing.

Ethics approval and consent to participate

All study participants provided written informed consent and the study was approved by Ethics and Research Committee (CEP) under the number CAAE: 41887715.0.0000.5503 and in the Clinical Trials database under the number NCT03105440.

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Availability of data and materials
The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions
ILM: drafted the initial manuscript; contributed to data acquisition and data analysis; contributed to the interpretation of the results.

FHMO: contributed to data acquisition and data analysis; contributed to the interpretation of the results.

GASS: designing the data.

TPS: designing the data.

FPSL: contributed to the conception and design of the study.

AOA: contributed to data acquisition and data analysis; contributed to the interpretation of the results.

MOL: contributed to the conception and design of the study.

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