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RESEARCH

Preventive effects of progressive resistance training of different intensities on breast cancer–related lymphedema

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Abstract

Purpose Explore the preventive effects of varying intensity progressive resistance exercise on breast cancer-related lymphedema.

Methods A total of 114 breast cancer patients who underwent axillary lymph node dissection at Tangshan People's Hospital from January to April 2024 were included. Participants were randomly assigned to three groups: the control group received conventional care; intervention group 1 received conventional care + low-intensity progressive resistance exercise; and intervention group 2 received routine nursing + moderate and high-intensity progressive resistance exercise. Body composition and grip strength were assessed pre-intervention, post-intervention, and at 3 and 6 months follow-up to compare differences among the groups.

Results (1) Body composition: At post-intervention, 3 and 6 months follow-up, segmental water differences and extracellular water ratios, along with 1- and 5-kHz SFBIA in both intervention groups, were lower than in the control group. Intervention group 2 had a lower extracellular water ratio than group 1 at post-intervention, and at 3 months follow-up, group 2 showed lower water differences and extracellular water ratios than group 1, with slight variations at 6 months ($P < 0.001$). (2) Grip strength: At post-intervention, 3 months and 6 months follow-up, grip strength in intervention group 1 and intervention group 2 was higher than that in control group, and the difference was statistically significant ($P < 0.001$).

Conclusion Resistance exercise enhances muscle strength and prevents lymphedema, with moderate-high-intensity exercise proving more effective than low intensity. Adverse events were minimal, suggesting that increasing resistance exercise intensity, while considering participants' conditions, may yield better preventive outcomes.

Keywords Breast cancer–related lymphedema · Resistance exercise · Body composition analysis · Rehabilitation nursing

Introduction

Breast cancer–related lymphedema (BCRL) is a serious postoperative complication for breast cancer patients, presenting clinical symptoms such as limb swelling, heaviness, tightness, and pain. In severe cases, it may also lead to fibrosis and recurrent infections [1]. Among women treated for breast cancer, the incidence is approximately 20% [2], while the likelihood of lymphedema in high-risk patients can be as high as 65% [3], making it difficult to treat once it occurs [4]. Among BCRL risk factors, axillary lymph node dissection is the primary treatment-related risk factor for BCRL in patients undergoing surgery, with a probability of BCRL as high as 65% [3]. Studies have indicated that individuals with ≥ 15 lymph nodes dissected are considered high-risk for BCRL [5]. Other treatment-related factors include extensive lymph node dissection, radiotherapy, chemotherapy with taxanes, and postoperative complications (such as infections) [6, 7]. Additionally, non-treatment-related independent risk factors include age ≥ 60 years, body mass index ≥ 25 kg/m^2 [8], physical inactivity, residing in metropolitan areas, and poor economic status [9, 10]. Progressive resistance training (PRT), as an important rehabilitation method after

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breast cancer surgery, not only contributes to muscle volume growth but also effectively enhances lymphatic circulation by activating muscle contractions. Consequently, the accumulation of lymphatic fluid in the affected limb may be alleviated [11]. Resistance exercise has been shown to improve quality of life, reduce economic burden [12], and enhance overall health [13]. Research indicates that resistance exercise may be an effective form of rehabilitation, and that supervised, slow, and gradual resistance and aerobic exercise training is safe for patients with BCRL or those at risk for BCRL [14] and does not cause edema [15–17]. Wang et al. [18] demonstrated that resistance exercise and physical activity can reduce the risk of edema. Furthermore, Wanchai et al. [19] and Hasenoehrl et al. [20] concluded that supervised resistance exercise may be safe, feasible, and beneficial for patients with breast cancer–associated edema and those at risk of developing it. The American College of Sports Medicine (ACSM) recommends that exercise prescriptions should adhere to certain principles, specifically the FITT principle, which encompasses exercise frequency, intensity, duration, and type [21]. While a set of resistance exercise training guidelines has been developed for healthy adults, there is no clear standard for the intensity of progressive resistance exercise for patients with breast cancer.

At present, there is no unified diagnostic standard for BCRL. In recent years, relevant studies have suggested that bioimpedance analysis may be of high value in the diagnosis of early-stage or subclinical lymphedema [22], and a common index is single-frequency bioimpedance analysis (SFBIA). Therefore, this study will design a randomized controlled trial to develop different-intensity progressive resistance exercise for breast cancer participants and use the InBody body composition analyzer to perform bioimpedance analysis to explore the preventive effect of personalized exercise prescription on BCRL in breast cancer postoperative participants.

Methods

Subjects

This prospective study enrolled 114 female breast cancer patients attending the Breast Surgery Department of Tangshan People's Hospital from January to April 2024 for concurrent surgical treatment. According to the parent study, the sample size of the randomized controlled trial was calculated based on the incidence of lymphedema using the following:

$$n = 1641.4\lambda / \left(sin\text{-}1\sqrt{P_{max}} - sin\text{-}1\sqrt{P_{min}} \right)^2$$

g is the number of groups, λ is the limit of degrees of freedom $\nu = g - 1$, which can be obtained by consulting the table; $P_{\max}$ and $P_{\min}$ were the maximum and minimum rates, $\alpha = 0.05$, $\beta = 0.1$, and $n = 32$ were calculated based on the reviewed data. On this basis, the follow-up loss rate was increased by 20%, resulting in 38 cases in each group, for a total of 114 cases. Using a random number table method, 114 patients who met the inclusion criteria were assigned numbers according to the order of inclusion. These 114 numbers were then transcribed sequentially from any starting number into a table of random numbers, with each number representing one of the 114 patients. All numbers were reordered from smallest to largest, with the first 38 corresponding to participants in the control group, the middle 38 corresponding to participants in intervention group 1, and the last 38 corresponding to participants in intervention group 2, who were unaware of the grouping.

Inclusion criteria are as follows: (1) patients diagnosed with breast cancer and undergoing axillary dissection; (2) patients with normal upper limb function before surgery; (3) patients without mental illness or communication disorders, who can correctly understand the content presented by the researcher; (4) patients who voluntarily participate in the research and sign the informed consent; (5) no resistance exercise in the month prior to enrollment. Exclusion criteria are as follows: (1) patients with deep phlebitis or thrombus in the affected limb; (2) patients with distant metastasis; (3) individuals with cardiovascular disease, ischemic vascular disease, acute skin inflammation, severe peripheral neuropathy, or joint disease should not engage in exercise. Criteria for dropping out are as follows: (1) those who request to withdraw during the study for personal reasons; (2) participants with poor compliance who interrupt exercise for 2 weeks or more without justification; (3) changing treatment hospitals, making it impossible to continue participating in the study. This study has been approved by the Ethics Committee of Tangshan People's Hospital (Ethics number: RMYY-LLKS-2024071).

Intervention methods

All the participants received routine care after surgery. Participants who had a Constant–Murley shoulder joint score ≥ 70 were treated for a total of 12 weeks. The intervention methods were as follows.

Control group: Routine nursing. The participants were instructed to perform fist and wrist flexion on day 2 after surgery, elbow flexion on days 3–4, palm touch on the affected side and auricle on the same side on days 5–6, shoulder exercises on days 7–8, finger climbing on days 9–13, and practice gradually placing the affected hand on the back of the neck on day 14. After the drainage tube was removed, shoulder abduction and other exercises were started 1–2

times/day. After discharge, participants were asked to continue with the exercises.

Intervention group: Routine nursing and progressive resistance exercise combined with aerobic exercise. The intervention plan was discussed and designed by an expert panel consisting of one international lymphedema therapist, one breast cancer case manager, two breast surgeons, two clinical nurse specialists in breast surgery, and one rehabilitation physician. The plan consisted of seven resistance movements: front arm flat lift, side arm flat lift, chest expansion, forearm flexion and extension, shoulder press, neck back arm flexion and extension, and bending and extension. The specific intervention methods are listed in Table 1.

The researchers involved in the intervention were uniformly trained and assessed for the consistency and accuracy of their teaching methods. After completing the assessments, they instructed the participants. Once the participants achieved the standard shoulder function, the researchers explained the exercise methods and possible adverse reactions, distributed exercise logs and training videos, and instructed participants to exercise at home after discharge. Regular follow-ups and evaluations were conducted at the hospital.

The muscle strength of the affected limb was assessed before the intervention. One-repetition maximum (1-RM) was indirectly measured and calculated based on the participant's weight at a maximum of 10 repetitions (75%1-RM) to establish the resistance exercise weight load. All the participants in the intervention group exercised while wearing a uniform pressure bandage (Pefitt, Grade III). If participants had muscle soreness or mild reversible edema symptoms during the intervention, the intervention was suspended, the affected limb's rest time was increased, weight-bearing was avoided, and the intervention was continued after relief. If the suspension lasted more than a week, the weight load was lowered, and the participants were instructed to gradually increase the weight load to avoid the recurrence of adverse reactions.

Measurement indicators

Participants' general data were recorded only before the intervention, and body composition analysis and grip strength assessment were performed at pre-intervention, post-intervention, and 3- and 6-month follow-ups. Data collection was carried out by the same investigator, who was unaware of the group assignments throughout the study.

Investigator self-made general information questionnaire

The questionnaire included questions on sociodemographic characteristics (age, body mass index [BMI], education, family location, and per capita monthly income) and disease status (lesion site, number of lymph nodes removed, and chemotherapy course).

Analysis of human body composition

A body composition analyzer was used to evaluate the difference in water content between the two upper limb segments (defined as the affected side compared to the healthy side), the extracellular water ratio of the affected limb, and 1- and 5-kHz SFBIA ratios [25] (defined as the healthy side/affected side) for early screening of lymphedema [26].

The participants were asked to empty their urine and bowels before taking measurements with the InbodyS10 body composition analyzer. During the measurement, the participants stood with their feet apart, their arms straight,

Table 1 Exercise intervention methods

Procedure	Content	Specific methods
Part 1	Deep breathing + warm-up	Deep breathing for 2 min, moving the body joints and muscles for 5 min
Part 2	Double upper limb resistance training	Low-load group: weight load 40–50%1-RM [23]. Participants took a sitting or standing position, held a water bottle or a water dumbbell in both hands, and slowly repeated the same movement with breathing: exhaling when the muscles contracted and inhaling when they relaxed. Pressure bandages were worn during exercise, and the movement was as slow as possible. Centrifugal movements, such as throwing arms, were to be avoided. A sequence of seven actions was prescribed. Each action was repeated 15–20 times, and 2–3 groups were performed each time. RPE scores of 13–15 points [24] were suitable for intensity. After every 4 weeks of intervention, the weight load was increased by 2–10%1-RM [21], up to a maximum of 70%1-RM Medium/high-load group: The weight load was 50–60%1-RM. Each movement was repeated 8–12 times, each time in 2–3 groups. After every 4 weeks of intervention, the weight load increased by 2–10%1-RM [21], up to a maximum of 80%1-RM
Part 3	Relaxation	Stretch the muscles for 5–10 min

and did not touch any side of their body. The ankles were exposed, the electrodes of the lower limbs were clipped on both sides of the ankle, and the electrodes of the upper limbs were clipped on both thumbs and middle fingers. Double upper limb segment water, extracellular water ratio of the affected limb, and 1- and 5-kHz double upper limb bioelectrical impedance values were recorded.

Grip strength assessment of affected limb

Using the same gripper, participants were asked to grip firmly to assess muscle strength in the affected limb. The test was repeated after a 2-min rest, and the average of three readings in kilograms (kg) was calculated.

Participant adverse event report

After 12 weeks of intervention, all adverse events were recorded. Severity was graded based on whether the participant had to stop a particular intervention (level 1) or totally end the intervention (level 2).

Statistical methods

Excel was used to establish the database, and SPSS (version 26.0) was used for statistical analysis of the data. Results of normally distributed variables are presented as mean ± standard deviation ($\bar{x} \pm s$). A single-factor ANOVA was used for intergroup comparisons. Non-normally distributed variables are presented as median and quartiles (M, P25, and P75). The Kruskal–Wallis *H* test was used for intergroup comparisons, and the Bonferroni method was used for post hoc comparisons. Grade data: statistical analysis of measurement data with non-normal distribution; counting data: frequency and percentage were used, and χ^2 test was used for comparison between groups. Variation trend of outcome indicators at different time points: in this study, all outcome indicators followed a non-normal distribution. The generalized estimation equation was used for analysis, and the non-equilibrium items of general data (such as whether radiotherapy was performed and the location of radiotherapy) were included as covariates to reduce their impact on the results. All statistical tests were bilateral, and the significance level was set at 0.05.

Results

Comparison of general data between the three participant groups

A detailed participation process flow chart is shown in Fig. 1. A total of 110 participants were included. In the control group of 37, 1 withdrew due to unwillingness to undergo BCRL follow-up monitoring, resulting in a follow-up loss rate of 2.6%. In intervention group 1, of 36 participants, 1

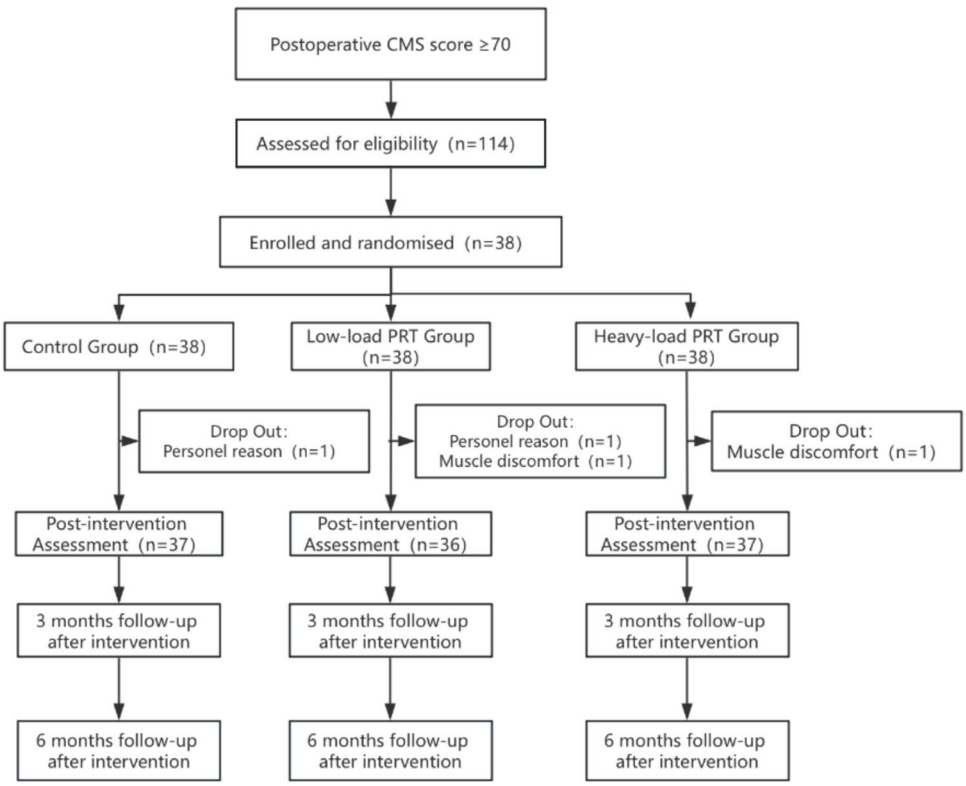

Fig. 1 Flow chart of the study participation process

withdrew due to muscle discomfort after 3 exercises, and another due to reluctance for follow-up, leading to a follow-up loss rate of 5.3%. In the two intervention groups with 37 cases, 1 withdrew for similar reasons, with a follow-up loss rate of 2.6%. There were no significant differences in general data among the three groups, except regarding radiotherapy and its location ($P > 0.05$) (Table 2).

Comparison of body composition analysis among the three participant groups

Before the intervention, there were no significant differences in segmental water difference, extracellular water ratio, and 1- and 5-kHz SFBIA among the three groups ($P > 0.05$). After the intervention, the segment water difference, extracellular water ratio, and 1- and 5-kHz SFBIA in intervention group 1 and intervention group 2 were lower than those the in the control group. The ratio of extracellular water in intervention group 2 was lower than that in intervention group 1, and the difference was statistically significant ($P < 0.001$). At 3-month follow-up, the segmental water difference, extracellular water ratio, and 1- and 5-kHz SFBIA in intervention group 1 and intervention group 2 were lower than those in the control group. The segment water difference, extracellular water ratio, and 1 SFBIA in intervention group 2 were lower than those in intervention group 1, with statistical significance ($P < 0.001$). At the 6-month follow-up, the segmental water difference, extracellular water ratio, and 1- and 5-kHz SFBIA in intervention group 1 and intervention group 2 were lower than those in the control group. The ratio of extracellular water in intervention group 2 was higher than that in intervention group 1, and the difference was statistically significant ($P < 0.001$). The results of generalized estimation equation analysis showed that the four indexes of the Inbody body composition analysis had statistically significant differences in intervention effect, time effect, and interaction effect ($P < 0.001$), indicating that the indexes of body composition analysis of participants had significant changes with the change of time and the implementation of intervention measures (Table 3).

Table 2 Comparison of general data between the three groups *n* (%)

Item	Classification	Control group ($n=37$)	Low-load group($n=36$)	Medium/ high-load group($n=37$)	$F/H/\chi^2$	P
Age		51.54 ± 4.57	49.11 ± 9.35	46.73 ± 10.98	2.808[a]	0.065
BMI		25.86 ± 3.88	25.38 ± 3.58	26.11 ± 3.66	0.358[a]	0.700
Educational level	Primary and below	7(18.9)	6(16.7)	3(8.1)	7.887[b]	0.247
	Junior high school	22(59.5)	18(50.0)	15(40.5)		
	Secondary or high school	5(13.5)	6(16.7)	10(27.0)		
	College and undergraduate	3(8.1)	6(16.7)	9(24.3)		
Home location	Village	22(59.5)	17(47.2)	15(40.5)	2.724[c]	0.256
	Town	15(40.5)	19(52.8)	12(59.5)		
Per capita monthly income	< 3000	11(29.7)	6(16.7)	4(10.8)	2.542[b]	0.281
	3000–5000	18(48.6)	23(63.9)	23(62.2)		
	> 5000	8(21.6)	7(19.4)	10(27.0)		
Tumor site	Left	18(48.6)	19(52.8)	25(67.6)	2.972[c]	0.226
	Right	19(51.4)	17(47.2)	12(32.4)		
Number of lymph nodes removed		19.57 ± 6.59	18.50 ± 9.12	20.43 ± 8.29	0.526[a]	0.592
Chemotherapy course	4	3(8.1)	1(2.8)	1(2.7)	8.740[c]	0.068
	6	12(32.4)	20(55.6)	24(64.9)		
	8	22(59.5)	15(41.7)	12(32.4)		
Radiotherapy or not	Yes	16(43.2)	24(66.7)	33(89.2)	17.498[c]	< 0.001
	No	21(56.8)	12(33.3)	4(10.8)		
Radiotherapy site	Breasts and chest wall	4(10.8)	3(8.3)	3(8.1)	16.235[c]	0.013
	Lymph node region	2(5.4)	2(5.6)	2(5.4)		
	All	12(32.4)	19(52.8)	28(75.7)		
	No	19(51.4)	12(33.3)	4(10.8)		

[a] *F*-value

[b] *H*-value

[c] Value of χ^2

Table 3 Comparison of Inbody composition analysis among the three groups M (P25, P75)

Item	Time	Control group ($n=37$)	Low-load group($n=36$)	Medium/ high-load group($n=37$)	H	P	P_{Group}	P_{time}	$P_{interaction}$
Segment moisture difference	Pre-intervention	−20(−70, 30)	−30(−80, 20)	−45(−105, −20)	5.687	0.058	<0.001	<0.001	<0.001
	Post-intervention	50(20, 95)	−10(−40, 15) [a]	−30(−50, −10) [a]	30.287	<0.001			
	3 months follow-up	100(50, 150)	−10(−20, 0) [a]	−25(−50, −10) [ab]	69.246	<0.001			
	6 months follow-up	100(50, 160)	−10(−20, −10) [a]	−10(−30, 0) [a]	72.040	<0.001			
Extracellular water ratio	Pre-intervention	0.382(0.380, 0.384)	0.382(0.379, 0.384)	0.383(0.379, 0.385)	0.208	0.901	<0.001	0.025	<0.001
	Post-intervention	0.386(0.383, 0.389)	0.382(0.380, 0.385) [a]	0.380(0.376, 0.383) [ab]	32.064	<0.001			
	3 months follow-up	0.390(0.386, 0.392)	0.380(0.379, 0.383) [a]	0.379(0.372, 0.380) [ab]	71.861	<0.001			
	6 months follow-up	0.390(0.387, 0.393)	0.376(0.370, 0.378) [a]	0.380(0.379, 0.383) [ab]	72.497	<0.001			
1 kHz SFBIA	Pre-intervention	0.989(0.976, 1.002)	0.991(0.963, 1.032)	0.980(0.940, 0.995)	4.216	0.121	<0.001	<0.001	<0.001
	Post-intervention	1.044(1.027, 1.095)	0.997(0.986, 1.008) [a]	0.987(0.953, 0.999) [a]	35.345	<0.001			
	3 months follow-up	1.113(1.067, 1.140)	0.996(0.993, 1.000) [a]	0.990(0.987, 0.995) [ab]	74.338	<0.001			
	6 months follow-up	1.120(1.079, 1.199)	0.994(0.991, 0.997) [a]	0.995(0.989, 1.003) [a]	71.806	<0.001			
5 kHz SFBIA	Pre-intervention	0.993(0.971, 1.000)	0.994(0.962, 1.030)	0.979(0.940, 0.997)	5.128	0.077	<0.001	<0.001	<0.001
	Post-intervention	1.044(1.031, 1.097)	0.998(0.986, 1.011) [a]	0.980(0.971, 0.999) [a]	34.840	<0.001	<0.001		
	3 months follow-up	1.115(1.068, 1.146)	0.996(0.991, 0.999) [a]	0.990(0.981, 0.996) [a]	74.101	<0.001	<0.001		
	6 months follow-up	1.120(1.081, 1.203)	0.995(0.992, 0.997) [a]	0.996(0.988, 1.004) [a]	72.111	<0.001			

SFBIA single-frequency bioimpedance analysis

Compared with the control group, [a]$P<0.05$; compared with the low-load group, [b]$P<0.05$

Comparison of grip strength between the three groups

Before the intervention, there was no significant difference in grip strength among the three groups ($P>0.05$). After intervention, at 3 months and 6 months follow-up, the grip strength of intervention group 1 and intervention group 2 was higher than that of the control group; the difference was statistically significant ($P<0.001$). However, there was no significant difference between intervention group 1 and intervention group 2 ($P>0.05$). The results of the generalized estimation equation analysis showed that grip strength had statistical significance in the intervention effect, time effect, and interaction effect ($P<0.001$), indicating that the grip strength of participants changed significantly with the change of time and the implementation of intervention measures (Table 4).

Participant-reported adverse events

No grade 2 adverse events were reported. Twenty-three participants reported grade 1 muscle soreness during the intervention period, including 11 (30.6%) and 12 (32.4%) in intervention groups 1 and 2, respectively. After 2–3 days of rest, 19 participants reported remission and were able to continue with the intervention. Two participants reported remission after resting for 1 week; weight and repetitions were reduced as appropriate after remission, and no adverse events were reported thereafter. Two participants feared exercise due to muscle soreness and refused to continue in the study, and their symptoms had subsided at follow-up. The results showed that the exercise program was safe and well tolerated by the participants.

Table 4 Comparison of grip strength among the three groups M (P25, P75)

Item	Time	Control group ($n=37$)	Low-load group($n=36$)	Medium/ high-load group($n=37$)	H	P	P_{Group}	P_{time}	$P_{interaction}$
Grip	Pre-intervention	12.5(11.0, 13.2)	12.4(11.3, 15.8)	11.3(10.8, 13.9)	2.570	0.277	< 0.001	< 0.001	< 0.001
	Post-intervention	11.2(10.2, 12.2)	13.6(12.1, 16.6) [a]	13.9(12.8, 16.0) [a]	37.131	< 0.001			
	3 months follow-up	10.7(9.6, 11.1)	14.5(12.8, 17.1) [a]	15.3(13.9, 16.9) [a]	60.982	< 0.001			
	6 months follow-up	10.3(9.7, 10.9)	15.1(13.3, 17.6) [a]	17.0(15.2, 18.3) [a]	66.548	< 0.001			

Compared with the control group, [a]$P < 0.05$

Discussion

BCRL is a serious complication following breast cancer surgery. For breast cancer survivors undergoing radical surgery, lymph node dissection, and postoperative adjuvant radiotherapy, the destruction of normal lymphoid tissue to some extent, obstruction of lymphatic reflux, retention of substantial amounts of protein-rich extracellular fluid in the subcutaneous tissue, and increased extravascular colloid osmotic pressure may occur. As a result, the reabsorption capacity of the capillaries is reduced, preventing extracellular fluid from returning to the bloodstream through the capillaries. Consequently, fluid from the capillaries enters the tissue space in large quantities under the pressure gradient, leading to fluid retention in the tissue space and the development of edema [27]. Thus, the volume of water in the affected limb segments and the extracellular fluid will gradually increase. In this study, all 110 participants were at high risk for BCRL. We developed a prescription for progressive resistance exercise of varying intensity to explore its preventive effect on BCRL. The results indicated that moderate- and high-intensity progressive resistance exercise had a positive effect on preventing BCRL.

Before intervention, the affected side's segmental water content was lower than the healthy side in all three groups. After intervention and at the 3-month follow-up, the conventional care group showed a gradual increase in segmental water content on the affected side, surpassing that of the healthy side, indicating fluid accumulation due to blocked lymphatic reflux. However, the water content of the affected side was still lower than that of the healthy side under the two interventions, indicating that progressive resistance exercise may partially compensate for lymphatic reflux disorder, promote lymphatic reflux, and delay the onset of BCRL. This also suggests that resistance exercise does not increase the risk of BCRL. Regarding the extracellular fluid water ratio, the ratio for participants in both interventions gradually decreased. Notably, the extracellular water ratio for participants in the medium–high-intensity group was lower than that in the conventional care group and the low-intensity group after the intervention and at the 3-month follow-up, while the ratio for participants in the conventional care group gradually increased.

The study suggests that breast cancer survivors may gradually develop BCRL after conventional surgery but that progressive resistance exercise can slow this trend, with moderate- to high-intensity exercise proving more effective. At the 6-month follow-up, the medium–high-intensity group's extracellular water ratio was lower than that of the conventional care group but slightly higher than that of the low-intensity group. This may be attributed to the high resistance load in the medium–high-intensity group and poor exercise adherence. Additionally, radiotherapy and its site significantly affected BCRL risk; the proportion of participants receiving radiotherapy was higher in both exercise groups compared to the conventional care group. However, changes in segment water difference and extracellular fluid water ratio were smaller than those in the conventional care group, further indicating that resistance exercise positively impacts BCRL prevention.

In terms of bioimpedance, the study calculated 1- and 5-kHz SFBIA to assess early BCRL. The results indicated that participants with 1- and 5-kHz SFBIA in both interventions had lower readings than those in the usual care group after the intervention and at the 3-month follow-up. After the intervention, the 1-kHz SFBIA and 5-kHz SFBIA in the medium–high-intensity group were lower than those in the low-intensity group, and the 1-kHz SFBIA remained lower than that in the low-intensity group at the 3-month follow-up, indicating that medium–high-intensity progressive resistance exercise was more effective in preventing BCRL. However, at the 6-month follow-up, there was no significant difference in 1- and 5-kHz SFBIA between the medium–high-intensity group and the low-intensity group, which may still be attributed to poor exercise compliance and adherence difficulties. Therefore, in the formulation of exercise prescriptions, a variety of exercise forms should be adopted to improve and maintain participant compliance, ensuring the effectiveness of the exercise. The American Physical Therapy Association (APTA) recommends the use

of Bioimpedance Analysis (BIA) for the detection of lymphatic transport disorders or subclinical/early lymphedema [22].

This method works by using low-frequency current, which cannot pass through cell membranes and mainly travels through extracellular fluid, allowing for direct measurement. The lymphedema index is calculated by measuring electrical impedance and the impedance ratio. As lymphatic fluid accumulates in interstitial spaces, extracellular fluid increases, leading to decreased current impedance in the affected limb and a rise in SFBIA. Lim et al. [28] found SFBIA cutoff values at 1 kHz and 5 kHz to be 1.049 and 1.047, respectively, with the 5-kHz ratio showing better performance (specificity 95.15%, sensitivity 63.64%). Their study indicated that the extracellular fluid moisture ratio in the conventional care group increased over time, and the median SFBIA surpassed the cutoff at the 3-month follow-up, while the intervention groups did not reach this value. This suggests that progressive resistance exercise can reduce extracellular fluid and mitigate BCRL, with medium- and high-strength exercises being more effective.

In terms of grip strength, participants in the two interventions experienced a significant increase, while those in the conventional care group saw a decrease. This indicates that resistance exercise can effectively improve the muscle strength of the affected limb. Currently, within the academic community's discussion of the BCRL prevention mechanism, the "muscle pump" theory is widely recognized. Through active muscle contraction, muscle endurance, strength, and function are enhanced [29]. This promotes lymphatic reflux and alleviates or prevents swelling and dysfunction in the limbs. Consequently, some scholars believe that appropriate resistance exercise can effectively prevent the occurrence of lymphedema after surgery [30]. The mechanism for BCRL prevention may involve active muscle relaxation and contraction movements, which promote lymphatic reflux and delay the onset of BCRL. Studies have shown [31] that, unlike the cardiovascular system, the lymphatic system lacks an organ to serve as a pump and must rely on both endogenous and exogenous forces to drive lymphatic formation and transport. External mechanisms include active and passive limb movements, pressure changes associated with breathing, and pulsations in nearby arteries, while intrinsic mechanisms involve spontaneous, intermittent contractions of the smooth muscle in the lymphatic endothelium. Additionally, contracted skeletal muscle increases the cross-sectional area of muscle fibers and compresses adjacent connective tissue and lymphatic vessels, causing lymph to be propelled in the proximal direction. The presence of endothelial microvalves and intralymphatic valves ensures that lymph moves toward the larger contractile lymphatic vessels without leaking from the initial lymphatic vessels. For example, initial lymphatic compression caused by skeletal muscle contraction forces the lymphatic valve to open while closing the endothelial microvalve, directing lymph toward the proximal end of the constricting lymphatic vessel. Therefore, resistance exercise can enhance lymphatic reflux and reduce lymphatic leakage through active muscle movement, compensating for the obstruction of lymphatic flow caused by surgical damage to the lymphatic system. As a result, the water content of the affected limb and the water ratio of extracellular fluid will not significantly increase in a short period, ultimately preventing or slowing the onset of BCRL.

The sports science literature demonstrates a dose–response relationship between elevated load and gains in muscle structure and function, indicating that heavier loads are more effective in inducing strength gains than lighter loads [21, 32]. Bloomquist et al. [33] found that the acute changes in extracellular fluid, arm volume, and BCRL-related symptoms were similar in women undergoing taxane chemotherapy during axillary lymph node dissection, regardless of whether they performed low-load or heavy-load upper extremity resistance exercise.

The L-Dex score decreased significantly after high-load resistance exercise, and BCRL symptoms were alleviated following this exercise. One study [34] found that in women with stable edema, engaging in resistance exercise with a load of 6–10 RM did not acutely worsen swelling or BCRL symptoms. This study showed consistent results: both low-intensity resistance exercises did not increase the risk or symptoms of BCRL, while higher-intensity resistance exercises had a more positive effect on improving muscle strength and lymphatic reflux. Approximately 30% of participants experienced adverse events during the intervention period, and no serious adverse events occurred. The most common adverse event was muscle discomfort, which also typically occurs in healthy individuals. The results indicate that this exercise prescription is relatively safe.

The limitation of this study is that the follow-up period after the intervention is short, and acute edema of the arm may result from surgery or chemotherapy shortly after surgery (3–4 months), which interferes with the measurement of BCRL. Although this study has extended the measurement period to 10–11 months after surgery, the follow-up time remains limited. The follow-up duration will be further extended to observe changes in BCRL risk and symptoms and to explore the effectiveness of exercise prescriptions in preventing BCRL.

To sum up, progressive resistance exercise can prevent or slow the onset of BCRL and increase muscle strength to some extent. The results of this study indicate that medium–high-intensity progressive resistance exercise is more effective than low intensity. Therefore, in clinical practice, personalized exercise prescriptions can be developed

for participants based on their specific conditions to achieve optimal postoperative rehabilitation outcomes.

Author contribution Zhang Zirui and Zhou Lizhi conceived and designed the study. Hu Jiwei, Du Aijun and Hao Xijun supervised the research progress. Zhang Zirui and Guo Luyan conducted data collection and sorting, data analysis and paper writing. All authors contributed to manuscript writing and finalization.

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Data availability No datasets were generated or analysed during the current study.

Declarations

Competing interests The authors declare no competing interests.

Ethics approval The project complies with the Declaration of Helsinki and Chinese medical ethics laws and was reviewed and approved by the Ethics Committee of Tangshan People's Hospital (approval number: 2024071).

Consent to participate All participants voluntarily provided informed consent upon enrollment in the study.

Consent for publication This study did not include any individual personal data.

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