Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Effects of a 12-Week Thoracic Compression Device Exercise Program After Breast Cancer Resection: Changes in Physiological Indicators and Shoulder Muscle Function

Ji-Myeong Park
Ain Hospital
Kang-Taek Lim
Ain Hospital
Hyun-Jae Woo
Wakayama Professional University of Rehabilitation
Jeong-Ha Lee
Korea University
Seong-Ki Lee
CHA University
Kyoung-Bin Min
Korea University
Myung-Ki Kim
kmk1905@korea.ac.kr

Korea University

Research Article

Keywords: Breast cancer, TCDE, NK cell activity, CRP, Rehabilitation

Posted Date: June 18th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9091014/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Abstract

Background

Breast cancer survivors often experience weakened immune function, inflammation, and shoulder dysfunction after surgery. This study evaluated the effects of a 12-week thoracic compression device exercise (TCDE) on immune markers, inflammation, and shoulder muscle function.

Methods

Fifty-one participants were randomly assigned to control (CON), breast cancer rehabilitation exercise (BCRE), or TCDE groups. Natural killer (NK) cell activity, C-reactive protein (CRP) levels, and shoulder isokinetic strength/endurance were measured pre- and post-intervention.

Results

TCDE showed the greatest increase in NK cell activity and the largest decrease in CRP levels ($p < 0.001$). Both TCDE and BCRE improved shoulder strength and endurance, with TCDE showing the most improvement. Changes in the CON group were minimal and clinically insignificant.

Conclusions

TCDE is an effective rehabilitation strategy for improving immune response, reducing inflammation, and restoring shoulder function in breast cancer survivors.

Background

Breast cancer (BC) is one of the most prevalent cancers among women worldwide, and its incidence continues to increase [1]. According to the Health Insurance Review and Assessment Service (HIRA), the number of BC patients in Korea has steadily risen from 97,008 in 2010 to 266,313 in 2024, indicating a growing social and economic burden associated with the disease [2]. The etiology of BC is associated with various factors, including age at menarche, aging, menopause, family history, genetic predisposition, and obesity [3]. Although no single cause has been clearly identified, the multifactorial nature of these risk factors has contributed to a continuous increase in both incidence and mortality rates.

With the implementation of national cancer screening programs and improvements in treatment quality, the 5-year and 10-year survival rates for BC patients have reached 90.1% and 84.6%, respectively [4]. As long-term survival rates continue to improve, the focus of BC management has shifted beyond mere

survival toward the restoration of immune function and the maintenance of overall health following treatment.

Immune function plays a critical role in suppressing tumor recurrence and preventing infection, requiring finely regulated interactions among various immune cells [5]. Among these, natural killer (NK) cells account for approximately 10–15% of peripheral blood lymphocytes and represent a key component of innate immunity by directly eliminating tumor cells and virus-infected cells. NK cell activity is highly responsive to lifestyle-related factors such as physical exercise and is widely used as an important indicator reflecting psychological stress and overall systemic health [6]. Furthermore, reduced NK cell function has been reported to facilitate tumor immune evasion and is associated with an increased risk of cancer recurrence and metastasis [7].

Meanwhile, C-reactive protein (CRP) is a representative acute-phase protein synthesized in the liver that rapidly increases in response to inflammation and sensitively reflects systemic inflammatory status. CRP is widely used not only for the diagnosis and prognostic evaluation of infections, autoimmune diseases, and cardiovascular disorders, but also as an important biomarker indicating the degree of systemic inflammation and tumor progression in cancer patients [8].

In BC, elevated CRP levels have been associated with tumor invasion, angiogenesis, and the promotion of metastasis. Moreover, CRP has been proposed as a predictive marker for various treatment-related complications, including adverse effects of radiotherapy, cardiovascular complications, depression, and postoperative pain syndromes [9, 10, 11].

Therefore, the concurrent assessment of NK cell activity and CRP levels provides an important basis for a comprehensive evaluation of immune function and systemic inflammatory status in BC patients, enabling more integrated predictions of recurrence risk, potential complications, and treatment responsiveness.

Primary treatment approaches for BC include partial mastectomy, skin-sparing mastectomy (SSM), nipple-sparing mastectomy (NSM), and implant-based breast reconstruction (IBBR) with preservation of the pectoralis major fascia [12, 13, 14], while total mastectomy is also commonly performed [15]. Secondary treatments typically involve a combination of targeted therapy, endocrine therapy, radiotherapy, and systemic chemotherapy [16].

Women undergoing mastectomy for BC often experience a range of musculoskeletal symptoms resulting from lymph node dissection, removal of the pectoralis minor and breast tissue, and injury to the intercostal nerves. These sequelae commonly include reduced shoulder range of motion, muscle weakness, a sensation of thoracic compression, and persistent pain, which collectively lead to limitations in activities of daily living and a decline in quality of life [17, 18].

Methods

Study design

This study was conducted with approval from the Institutional Review Board of Changwon National University (Approval No.: 7001066-202502-BR-001; Approval Date: March 1, 2025). The participants were 63 female BC survivors aged between 40 and 59 years who had been hospitalized and were receiving rehabilitation treatment at Ain Hospital in Incheon, Republic of Korea, and who were at least three months post-mastectomy. All participants received a detailed explanation of the study procedures and provided written informed consent prior to participation. They were then randomly assigned to one of three groups: thoracic compression device exercise (TCDE), breast cancer rehabilitation exercise (BCRE), or a control group (CON).

Sample size estimation was performed using G-Power version 3.1.9.7 (Heinrich-Heine-Universität Düsseldorf, Germany) based on a repeated-measures analysis of variance (within–between interaction). The calculation assumed an effect size of f = 0.45, a significance level of α = 0.05, and a statistical power of 1 − β = 0.80. These parameters were determined based on previous rehabilitation exercise studies involving BC survivors [19]. To account for potential dropouts, the target sample size was set at 63 participants.

During the study, 12 participants withdrew due to time constraints or nonadherence to the intervention protocol. Consequently, a total of 51 participants completed the 12-week intervention and post-intervention assessments and were included in the final analysis. The dropout rate was 19%, which is within the generally acceptable range of less than 20% for clinical exercise intervention studies [20]. The final sample consisted of 17 participants in the TCDE group, 18 in the BCRE group, and 16 in the CON group. The physical characteristics of the participants are presented in Table 1.

Table 1
Participant characteristics.

	Sex	Involved		Age (years)	Height (cm)	Weight (kg)	BMI (kg/m^2)
	F	Rt	Lt				
CON	16	10	6	51.44 ± 9.43	162 ± 7.1	60.13 ± 5.21	22.95 ± 2.01
BCRE	18	10	8	57.28 ± 9	162.5 ± 6.57	62.44 ± 10.35	23.49 ± 2.34
TCDE	17	8	7	54 ± 7.3	159.18 ± 7.19	56.65 ± 9.46	22.23 ± 2.61

Data are presented as the mean ± standard deviation. F: female, Rt: right, Lt: left, BMI: body mass index, CON: control group, BCRE: Breast Cancer Rehabilitation Exercises, TCDE: Thoracic compression device exercise.

All participants commonly received 50 minutes of lymphatic manual therapy per session. The exercise intervention was conducted twice weekly for a total of 24 sessions, with each session lasting approximately 50 minutes. The program consisted of three phases: warm-up, main exercise, and cool-down. All exercises were performed by participants who had received medical clearance from the

attending physician confirming no restrictions on moderate-intensity exercise, and the interventions were safely supervised by certified exercise specialists.

Pre- and post-intervention assessments were conducted for approximately 81 minutes each. Outcome measures included immune function (NK cell activity), inflammatory response (CRP levels), and isokinetic shoulder muscle function. The experimental procedure and study design are illustrated in Fig 1.

Blood Sampling Protocol

For the analysis of measurement variables, venous blood samples were collected directly by a breast surgeon involved in this study. Participants who consented to blood collection were instructed to refrain from taking any medications, caffeine, or other substances that could potentially influence the experiment results, and to maintain at least 12 hours of rest prior to sampling. Before blood collection, participants arrived at the laboratory one hour in advance to ensure adequate rest [21]. Blood analyses were conducted at the designated institution, and both NK cell activity and CRP were measured and evaluated.

NK Cell Activity Assay

NK cell activity was quantified by selectively stimulating peripheral blood NK cells with an activating reagent and measuring the concentration of interferon-γ (IFN-γ) released into the culture supernatant using an enzyme-linked immunosorbent assay (ELISA) [22, 23, 24]. This assay provides an indirect evaluation of innate and tumor immune competence. All measurements were performed with the NK Vue® Gold Kit (ATGen, Republic of Korea) and a Sunrise™ microplate reader (TECAN, Austria) in accordance with the manufacturer's instructions. Reference categories were defined as normal (≥ 500 pg/mL), caution (250–500 pg/mL), borderline (100–250 pg/mL), and low (< 100 pg/mL) IFN-γ [25].

CRP levels

CRP was quantitatively measured in the central laboratory using an automated chemistry analyzer, cobas c 503 (Roche Diagnostics, Mannheim, Germany), together with the Tina-quant® CRP reagent based on the immunoturbidimetric assay. All analyses were performed in accordance with the manufacturer's instructions, and results were reported in mg/L.

Venous blood samples were collected, and the specimen type was standardized as either serum or lithium heparin plasma in accordance with the institutional standard operating procedures (SOP). Plasma was allowed to clot and then centrifuged (approximately 10–15 min) to separate the supernatant, whereas plasma samples were immediately mixed after collection and subsequently centrifuged. When analysis was delayed, specimens were stored at 2–8°C, and for long-term storage,

samples were frozen at − 20°C or lower and thawed only once prior to analysis. Samples exhibiting hemolysis, icterus, or lipemia were re-collected or reprocessed according to the institutional SOP prior to analysis. Laboratory values for CRP vary across institutions, and no standardized reporting method currently exists. Results are generally expressed in mg/dL or mg/L, while High-sensitivity C-reactive protein (hsCRP) is typically reported in mg/dL. Interpretation of CRP and hsCRP is essential for evaluating inflammation levels, monitoring disease progression, guiding treatment strategies, and identifying potential complications [26].

Isokinetic Muscle Function

Isokinetic muscle strength and endurance of the shoulder joint, particularly external rotation (ER) and internal rotation (IR), were evaluated using the Biodex System 4 Pro (Biodex Medical Systems, Shirley, NY, USA). Prior to testing, participants performed three practice trials for each item, with a 30-second rest interval provided between assessments. All shoulder joint movements, ER and IR were carried out within a pain-free range of motion. Isokinetic exercise was performed at constant angular velocities, with muscle strength assessed at 60°/sec for 5 repetitions and muscular endurance evaluated at 180°/sec for 10 repetitions. Peak torque values were recorded to determine maximal muscle performance. These outcomes were used to evaluate the extent of recovery of shoulder muscle function and to analyze functional changes following the intervention. The total duration of the assessment was approximately 15 minutes [27].

Exercise Programs

The exercise intervention program in this study was implemented for BC survivors who were at least three months post-mastectomy. The program was conducted twice weekly for 12 weeks, with each session lasting 50 minutes. Prior to the initiation of the intervention, all participants received manual lymphatic drainage (MLD) administered by a physical therapist to facilitate lymphatic circulation, after which they participated in the exercise program within a safe range of upper-extremity motion.

All exercises were performed only by participants who had received medical clearance from the attending physician confirming that moderate-intensity exercise posed no contraindications. The entire intervention was consistently supervised by an experienced trainer to ensure both safety and uniformity of exercise execution.

Each exercise session consisted of three phases: a warm-up (10 minutes), a main exercise phase (10–15 minutes), and a cool-down (10 minutes). The main exercise component was designed as a progressive resistance training program using Thera-Band®. The primary exercises targeted shoulder joint flexion, extension, external rotation, and internal rotation, with the aim of restoring upper-extremity muscle strength and functional capacity. Band resistance was progressively increased across the intervention period: a yellow band (low intensity) was used during weeks 1–3, a red band (moderate intensity) during weeks 4–8, and a green band (high intensity) during weeks 9–12. Based on a 100%

elongation length, Thera-Band® resistance corresponds to mean tensile forces of approximately 15.7% (yellow), 21.1% (red), and 23.5% (green) [28].

Exercise intensity was maintained at a Rating of Perceived Exertion (RPE) level of 11–13, allowing for gradual muscular adaptation while minimizing excessive physical strain (Table 2).

Table 2
Exercise programs

Warm	**Index**	**Exercise**	**Intensity**	**Side**
up	**Flexibility**	**Begin gentle T-bar ROM exercises of the shoulder** **(flexion, extension, abduction, horizontal adduction, ER, IR)**	**1–12 weeks** **(5 s×10 reps) × 3 sets** **10min**	**Involved**
Intensive muscle exercise	Isotonic	Band front raise Band lateral raise Band shoulder press Band shoulder ER Band shoulder IR	1–12 weeks 10 reps × 3 sets	Both
Cool down	Stretching	Foam roller stretching	10 min	Both
ROM: range of motion, ER: external rotation, IR: internal rotation				

Thoracic Compression Device Exercise (TCDE)

Participants in the TCDE performed thoracic mobility exercises using the ReaLine Core® device (GLAB Corp, Japan). This device was worn around the thoracic region to apply symmetrical anterior compression, thereby promoting lateral expansion and mobility of the middle- and lower thoracic spine. Simultaneous movements of the shoulder joints were incorporated to enhance the flexibility of the surrounding thoracic musculature. This combined approach facilitates improved thoracic alignment and mobility, contributing to better shoulder joint function [29] (Fig. 2).

Breast cancer rehabilitation exercises (BCRE)

The BCRE program in this study was reconstructed based on the exercise guidelines recommended in the clinical practice guidelines of the Korean Society of Lymphedema [30] and on the postoperative exercise principles proposed by a globally recognized BC specialist at the Comprehensive Breast Health Center of Brigham and Women's Hospital [31] (Fig. 2).

Control group (CON)

The CON consisted of BC survivors who had at least three months post-mastectomy and received MLD only, without any exercise intervention. MLD was administered by an experienced physical therapist according to a standardized protocol, with sessions conducted twice weekly for 12 weeks, each lasting 50 minutes, once lymphatic circulation had stabilized. This CON condition was established to examine the effects of MLD alone and to evaluate the additional benefits of exercise by comparison with the exercise intervention groups.

Statistical Analysis

Data was analyzed using IBM SPSS Statistics version 22.0 (SPSS Corp., Chicago, IL, USA). Means and standard deviations were calculated for all measurement variables across the three groups. A two-way repeated measures analysis of variance (ANOVA) was performed to examine the main effects of time (pre-intervention and post-intervention) and group (TCDE, BCRE, CON) during the 12-week training period, as well as the interaction effects between these two independent variables. Post hoc comparisons were conducted using the Tukey method, with Bonferroni adjustment applied to the confidence intervals. For significant interaction effects, paired-sample t-tests were performed to assess within-group differences between pre- and post-intervention, and independent-sample t-tests were used to evaluate between-group differences. Statistical significance was set at $\alpha = 0.05$ for all analyses.

Prior to conducting the two-way repeated measures ANOVA, the relevant statistical assumptions were examined. Normality was assessed using the Shapiro–Wilk test, homogeneity of variance was confirmed with Levene's test, and sphericity was evaluated using Mauchly's test. When violations of sphericity were detected, the Greenhouse–Geisser correction was applied. All assumptions were satisfied or appropriately corrected before the final analysis was performed.

Results

Changes in NK cell activity

Table 3. presents the changes in NK cell activity. The two-way repeated measures ANOVA revealed a significant main effect of group [$F(2,48) = 16.919$, $p < 0.001$], a significant main effect of time [$F(1,48) = 125.064$, $p < 0.001$], and a significant group × time interaction [$F(2,48) = 22.837$, $p < 0.001$].

At baseline, there were no statistically significant differences in NK cell levels among the groups. Following 12 weeks of intervention, the TCDE demonstrated significantly greater increases in NK cell levels compared with both the CON ($p < 0.001$) and BCRE ($p < 0.001$) groups. Furthermore, the BCRE exhibited a significant improvement compared with the CON ($p < 0.05$).

Paired t-tests within each group indicated significant pre- to post-intervention increases: CON ($t = -3.393$, $p = 0.004$), BCRE ($t = -5.804$, $p < 0.001$), and TCDE ($t = -9.222$, $p < 0.001$). Among these, the TCDE

showed the most pronounced enhancement in NK cell levels, suggesting that TCDE provide superior immunological benefits compared with the other interventions (Fig. 3a).

Table 3 Changes in NK cell activity. **Units: pg/mL**

Group	Pre	Post	Paired *t*-test		Two-way RM ANOVA			
			t-Value	*p*-Value		G	T	G×T
CON (n = 16)	242.88 ± 108.07[a]	678.25 ± 537.58[a]	-3.393	0.004**	*F*	16.919	125.064	22.837
BCRE (n = 18)	209.61 ± 106.12[a]	1408.11 ± 901.16[a]	-5.804	0.001***	*p*	0.001***	0.001***	0.001***
TCDE (n = 17)	194.59 ± 107.32[a]	2649.76 ± 1166.92[b]	-9.222	0.001***				

Data are presented as the mean ± standard deviation. Two-way RM ANOVA: two-way repeated measures analysis of variance. pg/mL: picogram per milliliter, CON: control group, BCRE: breast cancer rehabilitation exercise, TCDE: thoracic compression device exercise, G: group, T: time, G×T: group × time. Values marked with different lowercase letters indicate a statistically significant difference between groups ($p < 0.05$). Significant differences in pre- and post-test values ($p < 0.05$). * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Changes in CRP levels

Table 4. presents the changes in CRP levels. The two-way repeated measures ANOVA revealed a significant main effect of time [$F(1,48) = 55.712$, $p < 0.001$] and a significant group × time interaction [$F(2,48) = 8.013$, $p = 0.001$], whereas the main effect of group was not statistically significant [$F(2,48) = 2.308$, $p = 0.110$].

At baseline, no significant differences in CRP levels were observed among the groups. After the 12-week intervention, both the TCDE and BCRE groups demonstrated significantly greater reductions in CRP compared with the CON group ($p < .001$). However, the post-test CRP levels did not differ significantly between TCDE and BCRE. Importantly, this indicates that although the groups did not differ in absolute CRP levels, the magnitude of reduction over time was significantly different, with TCDE and BCRE showing larger decreases than CON.

Although the paired t-test values were positive, the CRP levels in all groups clearly decreased from pre- to post-intervention, indicating statistically significant reductions. Specifically, paired t-tests within each group showed significant declines in CRP levels: CON ($t = 4.611$, $p < 0.001$), BCRE ($t = 5.527$, $p < 0.001$), and TCDE ($t = 4.868$, $p < 0.001$). Among these, the TCDE demonstrated the largest absolute reduction in

CRP levels. This finding indicates that TCDE elicits a more pronounced anti-inflammatory response compared with conventional rehabilitation or CON conditions. Such improvements could be attributed to the combined effects of thoracic mobility stimulation, enhanced lymphatic circulation, and subsequent reduction in pro-inflammatory mediators, which together may play a pivotal role in improving long-term health outcomes (Fig. 3b).

Table 4 Changes in CRP **Units: mg/dL**

Group	Pre	Post	Paired *t*-test		Two-way RM ANOVA			
			t-Value	*p*-Value		G	T	G×T
CON (*n* = 16)	13.59 ± 11[a]	7.16 ± 6.51[a]	4.611	0.001***	*F*	2.308	55.712	8.013
BCRE (*n* = 18)	12.47 ± 9.55[a]	3.68 ± 3.7[b]	5.527	0.001***	*p*	0.110	0.001***	0.001***
TCDE (*n* = 17)	12.98 ± 10.38[a]	1.48 ± 2.03[b]	4.868	0.001***				

Data are presented as the mean ± standard deviation. Two-way RM ANOVA: two-way repeated measures analysis of variance. mg/dL: milligrams per deciliter, CON: control group, BCRE: breast cancer rehabilitation exercise, TCDE: thoracic compression device exercise, G: group, T: time, G×T: group × time. Values marked with different lowercase letters indicate a statistically significant difference between groups ($p < 0.05$). Significant differences in pre- and post-test values ($p < 0.05$). * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Changes in Shoulder ER and IR Muscle Strength at 60°/sec

Table 5. presents the changes in shoulder ER and IR muscle strength at 60°/sec in BC survivors following intervention. For shoulder ER, the two-way repeated measures ANOVA revealed significant main effects of group [$F(2,48) = 791.503$, $p < 0.001$], time [$F(1,48) = 666.530$, $p < 0.001$], and a significant group × time interaction [$F(2,48) = 203.004$, $p < 0.001$]. At baseline, there were no significant differences among the groups. After 12 weeks, the TCDE demonstrated significantly greater improvements in ER strength compared with both the CON and BCRE groups ($p < 0.001$). Additionally, the BCRE showed significant improvement compared with the CON ($p < 0.001$). Paired t-tests indicated no significant change in the CON ($t = -3.482$, $p < 0.001$, but with limited clinical relevance), whereas significant pre- to post-intervention increases were observed in both the BCRE ($t = -11.203$, $p < 0.001$) and TCDE ($t = -26.463$, $p < 0.001$), with the greatest gains occurring in the TCDE.

For shoulder IR, the two-way repeated measures ANOVA revealed significant main effects of group [$F(2,48) = 13.875$, $p < 0.001$], time [$F(1,48) = 234.876$, $p < 0.001$], and a significant group × time interaction [$F(2,48) = 79.003$, $p < 0.001$]. At baseline, no significant differences were observed among groups.

Following 12 weeks of intervention, the TCDE demonstrated significantly greater improvements in IR strength compared with both the CON and BCRE groups ($p < 0.001$), while the BCRE also exhibited a significant increase compared with the CON ($p < 0.001$). Paired t-tests revealed no significant pre- to post-intervention difference in the CON ($t = -1.652$, $p = 0.119$), whereas both the BCRE ($t = -6.800$, $p < 0.001$) and TCDE ($t = -15.011$, $p < 0.001$) groups exhibited statistically significant increases.

Taking together, these findings indicate that TCDE elicited the most substantial improvements in shoulder ER and IR strength at 60°/sec in BC survivors, compared with conventional rehabilitation exercises or the CON condition (Fig. 4a).

Table 5 Changes in shoulder ER and IR muscle strength at 60°/sec. Units: N·m

	Group	Pre	Post	Paired *t*-test		Two-way RM ANOVA			
				t-Value	*p*-Value		G	T	G×T
ER	CON (*n* = 16)	10.8 ± 5.23[a]	11.72 ± 5.79[a]	-3.482	0.001***	*F*	791.503	666.530	203.004
	BCRE (*n* = 18)	10.84 ± 2.75[a]	18.92 ± 3.33[b]	-11.203	0.001***	*p*	0.001***	0.001***	0.001***
	TCDE (*n* = 17)	10.22 ± 2.79[a]	28.85 ± 3.8[c]	-26.463	0.001***				
IR	CON (*n* = 16)	14.98 ± 5.55[a]	15.71 ± 6.23[a]	-1.652	0.119	*F*	13.875	234.876	79.003
	BCRE (*n* = 18)	14.76 ± 5.94[a]	21.92 ± 4.94[b]	-6.800	0.001***	*p*	0.001***	0.001***	0.001***
	TCDE (*n* = 17)	14.64 ± 3.95[a]	32.8 ± 3.08[c]	-15.011	0.001***				

Data are presented as the mean ± standard deviation. Two-way RM ANOVA: two-way repeated measures analysis of variance. N·m: newton meter, ER: external rotation, IR: internal rotation, CON: control group, BCRE: breast cancer rehabilitation exercise, TCDE: thoracic compression device exercise, G: group, T: time, G×T: group × time. Values marked with different lowercase letters indicate a statistically significant difference between groups ($p < 0.05$). Significant differences in pre- and post-test values ($p < 0.05$). * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Changes in Shoulder ER and IR Muscle Endurance at 180°/sec

Table 6. presents the changes in shoulder ER and IR muscle endurance at 180°/sec in BC survivors following intervention. For ER, the two-way repeated measures ANOVA revealed significant main effects of group [$F(2,48) = 107.780$, $p < 0.001$], time [$F(1,48) = 332.301$, $p < 0.001$], and a significant group × time interaction [$F(2,48) = 66.840$, $p < 0.001$]. At baseline, there were no significant differences in ER endurance among groups. After 12 weeks of intervention, the TCDE demonstrated significantly greater improvements compared with both the CON and BCRE groups ($p < 0.001$). The BCRE also exhibited significantly higher ER endurance compared with the CON ($p < 0.001$). Based on the paired t-test results, the CON group showed a statistically significant increase ($t = -2.359$, $p = .032$); however, the magnitude of change did not reach the established MCID (Minimal Clinically Important Difference) and therefore cannot be considered clinically meaningful. In contrast, both the BCRE ($t = -15.068$, $p < .001$) and TCDE ($t = -11.967$, $p < .001$) groups demonstrated highly significant improvements, with changes that exceeded the MCID threshold, indicating clinically meaningful enhancement. Notably, the TCDE group exhibited the greatest effect.

For IR, the two-way repeated measures ANOVA revealed significant main effects of group [$F(2,48) = 9.570$, $p < 0.001$], time [$F(1,48) = 266.552$, $p < 0.001$], and a significant group × time interaction [$F(2,48) = 67.762$, $p < 0.001$]. At baseline, there were no significant differences between groups. Following 12 weeks of intervention, the TCDE showed significantly greater improvements in IR endurance compared with both the CON and BCRE groups ($p < 0.001$). The BCRE also demonstrated significantly higher IR endurance compared with the CON ($p < 0.001$). Paired t-tests revealed no significant change in the CON ($t = -2.010$, $p = 0.063$), while both the BCRE ($t = -7.856$, $p < 0.001$) and TCDE ($t = -16.773$, $p < 0.001$) groups exhibited statistically significant increases, with the TCDE again showing the largest improvement.

Taken together, these results indicate that TCDE elicited the most substantial improvements in both ER and IR muscle endurance at 180°/sec in BC survivors, suggesting its superiority over conventional rehabilitation exercises and CON conditions in enhancing shoulder muscular endurance (Fig. 4b).

Table 6 Changes in shoulder ER and IR muscle endurance at 180°/sec. Units: N·m

	Group	Pre	Post	Paired *t*-test		Two-way RM ANOVA			
				t-Value	*p*-Value		G	T	G×T
ER	CON (*n* = 16)	12.41 ± 5.33[a]	13.91 ± 5.88[a]	-2.359	0.032*	*F*	107.780	332.301	66.840
	BCRE (*n* = 18)	11.29 ± 2.44[a]	21.56 ± 2.59[b]	-15.068	0.001***	*p*	0.001***	0.001***	0.001***
	TCDE (*n* = 17)	12.69 ± 3.44[a]	28.75 ± 4.54[c]	-11.967	0.001***				
IR	CON (*n* = 16)	17.84 ± 6.28[a]	18.83 ± 8.37[a]	-2.010	0.063	*F*	9.570	266.552	67.762
	BCRE (*n* = 18)	17.2 ± 6.14[a]	25.34 ± 2.98[b]	-7.856	0.001***	*p*	0.001***	0.001***	0.001***
	TCDE (*n* = 17)	17.72 ± 4.45[a]	33.31 ± 3.25[c]	-16.773	0.001***				

Data are presented as the mean ± standard deviation. Two-way RM ANOVA: two-way repeated measures analysis of variance. N·m: newton meter, ER: external rotation, IR: internal rotation, CON: control group, BCRE: breast cancer rehabilitation exercise, TCDE: thoracic compression device exercise, G: group, T: time, G×T: group × time. Values marked with different lowercase letters indicate a statistically significant difference between groups ($p < 0.05$). Significant differences in pre- and post-test values ($p < 0.05$). * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Discussion

Effects of TCDE on NK Cell Activity after Mastectomy

Exercise is widely recognized as a supportive strategy for improving immune function and postoperative recovery in BC survivors. Prior studies have reported that progressive resistance and stretching programs help prevent secondary complications and improve functional outcomes after BC treatment [32], while longer-term resistance training contributes to improvements in both physical and psychological domains of quality of life [33]. Exercise-based rehabilitation has also been linked to enhanced NK cell activity, as shown in upper-limb ergometer training programs [34]. In addition,

compression-assisted resistance exercise has been reported to improve NK cell function among BC survivors at risk for lymphedema, although the compression site differed from the thoracic region targeted in the present TCDE protocol [35].

Consistent with these reports, early postoperative recovery has been associated with measurable increases in NK cell activity, and regular exercise has been suggested to promote immune restoration during cancer survivorship [36]. In the present study, NK cell activity increased significantly after 12 weeks in the TCDE group compared with both the CON and BCRE groups, supporting TCDE as a feasible rehabilitation strategy for immune-related recovery.

Exercise intensity appears to be an important modifier of immune responses. Excessively high-intensity exercise may suppress immune function and reduce NK cell activity [37], whereas very low-intensity activity may be insufficient to induce meaningful changes [38]. Thus, the observed improvement in NK cell activity following TCDE may be interpreted as a physiological adaptation consistent with the benefits of regular moderate-intensity exercise. Furthermore, acute exercise is known to mobilize NK cells via increased blood flow, catecholamine responses, and cytokine-related mechanisms such as IL-6 signaling [39]. Collectively, these findings suggest that TCDE contributes to postoperative immune recovery in BC survivors, while longer-term follow-up studies are still needed to determine durability and underlying cellular mechanisms.

Effects of TCDE on CRP Levels after Mastectomy

Systemic inflammation in cancer patients may arise from tumor-related hypoxia, necrosis, and tissue injury, and is commonly observed during disease progression and treatment recovery [40]. CRP is an acute-phase protein synthesized in the liver and is widely used as a sensitive marker of systemic inflammation [41]. Elevated CRP has been reported as a prognostic indicator associated with cardiovascular risk and poorer survival outcomes in cancer, including BC [42, 43, 44]. Clinical studies consistently show higher CRP levels in cancer patients than in healthy CON [45, 46].

Although evidence on exercise–CRP associations can vary by population and program characteristics, many studies indicate that regular aerobic and resistance exercise reduces circulating CRP, supporting an anti-inflammatory adaptation to chronic training [47, 48, 49]. In contrast, acute high-intensity activity may transiently increase CRP through short-term tissue stress and inflammatory signaling [50].

In the present study, CRP decreased significantly across groups after 12 weeks, with the TCDE group showing the greatest reduction, suggesting that TCDE may provide added benefit in attenuating systemic inflammation beyond general activity. A plausible mechanism is that thoracic compression combined with mobility stimulation may enhance soft-tissue circulation and lymphatic return, facilitating clearance of inflammatory mediators. Compression-based approaches have been shown to improve inflammatory and clinical outcomes in other postoperative contexts [51]. More directly, manipulative/compressive interventions have been associated with increased thoracic duct lymphatic flow [52], and compression therapy has been reported to reduce CRP and symptoms in inflammatory

conditions [53]. Taken together, TCDE may serve as a practical exercise-based approach for modulating inflammation in BC survivors, although longitudinal research is needed to clarify whether CRP reductions translate into long-term clinical benefits.

Effects of TCDE on Shoulder Function (ER/IR Strength and Endurance)

Shoulder dysfunction is a common sequela after BC surgery, and multiple studies support the role of rehabilitation exercise in improving ROM and pain-related outcomes. Postoperative physiotherapy and structured exercise programs have demonstrated beneficial effects on shoulder mobility and functional recovery [54]. Nevertheless, the magnitude and consistency of these effects appear to depend on the specific design and content of the rehabilitation program. Accumulating evidence suggests that interventions incorporating scapulothoracic coordination and sensorimotor demands yield superior functional outcomes. For instance, a scapula-oriented shoulder exercise program emphasizing scapulothoracic motion produced significantly greater improvements in shoulder strength, ROM, and physical function than general exercise or CON conditions in BC survivors [55]. Furthermore, sensorimotor-focused rehabilitation has been shown to enhance dynamic shoulder stability by improving neuromuscular CON and coordinated movement patterns [56]. Taken together, these findings indicate that the integration of thoracic–scapular–shoulder mechanics with sensorimotor components is a critical determinant of optimal shoulder recovery following BC surgery.

In this study, a two-way repeated-measures ANOVA demonstrated significant time and group effects and a time×group interaction for shoulder strength and endurance, with post-hoc results indicating that TCDE produced greater improvements than BCRE and CON conditions. These findings suggest that TCDE may facilitate recovery not only of general shoulder capacity but also of velocity-dependent performance (strength/endurance), which is clinically relevant for functional activities. Mechanistically, the compressive and mobilizing stimuli applied to the thoracic region may improve scapulothoracic rhythm and mechanical efficiency of shoulder movement, thereby contributing to functional gains [57].

Overall, TCDE appears to be a multidimensional rehabilitation strategy that may support immune-related recovery (NK activity), inflammatory modulation (CRP levels), and shoulder functional improvement after mastectomy. Nevertheless, because the current study focused on short-term outcomes, future studies should investigate whether these benefits are sustained and whether functional improvements are associated with longer-term recovery indicators such as activities of daily living (ADL), quality of life (QoL), recurrence risk, and survival.

Conclusion

This study examined the effects of a 12-week TCDE program on immune function, inflammatory response, and shoulder muscle function in BC survivors following mastectomy. Compared with the BCRE and CON, the TCDE demonstrated a significant increase in NK cell activity and a greater reduction in CRP

levels, indicating enhanced immune function and attenuated systemic inflammation. In addition, TCDE resulted in superior improvements in isokinetic shoulder muscle strength and endurance.

Overall, these findings suggest that TCDE is an effective and integrative rehabilitation intervention that simultaneously promotes immune recovery, modulates inflammatory responses, and improves shoulder musculoskeletal function in BC survivors after mastectomy.

Recommendations

The present study demonstrated that a 12-week TCDE program effectively improved immune function, reduced inflammatory responses, and enhanced shoulder muscle function in BC survivors following mastectomy. These findings indicate that TCDE may serve as a complementary intervention to conventional rehabilitation exercises and has potential for early clinical application in hospital-based rehabilitation settings.

Based on the results of this study, several recommendations for future research and clinical practice are proposed. First, although TCDE was applied to survivors who were at least three months post-mastectomy, future studies should investigate the effects of initiating TCDE during the early postoperative period, as earlier intervention may further facilitate immune recovery, inflammation CON, and prevention of shoulder dysfunction. Second, longitudinal studies are warranted to evaluate the long-term sustainability of TCDE effects, including outcomes such as recurrence rate, survival rate, and quality of life. Third, future research should clarify the physiological mechanisms underlying TCDE, particularly its influence on blood flow and lymphatic circulation, by incorporating objective measures such as blood flow volume, tissue oxygen saturation, and lymphatic movement. Fourth, the development of standardized methods to quantify compression intensity is necessary to improve the reproducibility and clinical applicability of TCDE protocols. Finally, personalized TCDE strategies that account for individual factors such as age, cancer stage, surgical type, and comorbidities should be explored to optimize therapeutic outcomes.

Collectively, these recommendations suggest that TCDE has the potential to evolve into a comprehensive rehabilitation strategy that supports multidimensional recovery in BC survivors and enhances its clinical relevance and applicability.

Abbreviations

BC
Breast cancer
HIRA
Health Insurance Review and Assessment Service
NK
Natural Killer
CRP

C-Reactive Protein
SSM
Skin-Sparing Mastectomy
NSM
Nipple-Sparing Mastectomy
IBBR
Implant-Based Breast Reconstruction
TCDE
Thoracic Compression Device Exercise
BCRE
Breast Cancer Rehabilitation Exercise
CON
Control group
IFN-γ
Interferon-γ
ELISA
Enzyme-Linked Immunosorbent Assay
SOP
Standard Operating Procedures
hsCRP
High-sensitivity C-Reactive Protein
ER
External Rotation
IR
Internal Rotation
MLD
Manual Lymphatic Drainage
F
Female
Rt
Right
Lt
Left
BMI
Body Mass Index
pg/mL
picogram per milliliter
mg/dL
milligrams per deciliter
N·m

Newton meter
G
Group
T
Time
G×T
Group × Time

Declarations

Supplementary Information

Supplementary materials include additional tables and figures supporting the findings of this study. These are available from the corresponding author upon reasonable request.

Ethics approval and consent to participate

This study was approved by the Institutional Review Board of Changwon National University (Approval No.: 7001066-202502-BR-001; Approval Date: March 1, 2025). All participants provided written informed consent prior to participation.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Funding

This study received no external funding.

Author Contribution

Author ContributionsConceptualization: JMP, MKKMethodology: JMP, KTL, HJWInvestigation: JMP, JHL, KBMFormal analysis: JMP, KBMData curation: JMP, JHL, KBMWriting – original draft: JMPWriting – review & editing: KTL, HJW, SKL, MKKSupervision: MKKAll authors read and approved the final manuscript.

Acknowledgements

Not applicable.

Data Availability

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

References

1. Rojas K, Stuckey A. Breast cancer epidemiology and risk factors. Clin Obstet Gynecol. 2016;59(4):651–72.
2. Health Insurance Review & Assessment Service (HIRA). HIRA Bigdata Open Portal: the number of patients visiting hospitals for breast cancer. 2025. (Accessed 2025 Jan 16). https://opendata.hira.or.kr/op/opc/olap3thDsInfoTab2.do
3. Halverstadt A, Leonard A. Essential exercises for breast cancer survivors: how to live stronger and feel better. Boston (MA): Harvard Common; 2000.
4. Korea Central Cancer Registry, National Cancer Center. Annual report of cancer statistics in Korea in 2017. Ministry of Health and Welfare; 2019.
5. Vitlic A, Lord JM, Phillips AC. Stress, ageing and their influence on functional, cellular and molecular aspects of the immune system. Age (Dordr). 2014;36(3):9631–6.
6. Idorn M, Hojman P. Exercise-dependent regulation of NK cells in cancer protection. Trends Mol Med. 2016;22(7):565–77.
7. Grosse L, Hoogenboezem T, Ambree O, Bellingrath S, Jorgens S, de Wit HJ, et al. Deficiencies of the T and natural killer cell system in major depressive disorder: T regulatory cell defects are associated with inflammatory monocyte activation. Brain Behav Immun. 2016;54:38–44.
8. Allin KH, Nordestgaard BG, Flyger H, Bojesen SE. Elevated pre-treatment levels of plasma C-reactive protein are associated with poor prognosis after breast cancer: a cohort study. Breast Cancer Res. 2011;13(3):R55.
9. Gupta A, Oyekunle T, Salako O, Daramola A, Alatise O, Ogun G, et al. Association of high-sensitivity C-reactive protein and odds of breast cancer by molecular subtype: analysis of the MEND study. Oncotarget. 2021;12(13):1230–42.
10. Hu JJ, Urbanic JJ, Case LD, Takita C, Wright JL, Brown DR, et al. Association between inflammatory biomarker C-reactive protein and radiotherapy-induced early adverse skin reactions in a multiracial/ethnic breast cancer population. J Clin Oncol. 2018;36(24):2473–82.
11. Zhang AY, Ganocy SJ, Owusu C, Gao K. Associations among irritability, high-sensitivity C-reactive protein/interleukin-6, and depression in early-stage breast cancer during chemotherapy. J Acad

Consult Liaison Psychiatry. 2022;63(3):260–7.

12. Veronesi U, Stafyla V, Petit JY, Veronesi P. Conservative mastectomy: extending the idea of breast conservation. Lancet Oncol. 2012;13(7):e311–7.
13. Albornoz CR, Bach PB, Mehrara BJ, Disa JJ, Pusic AL, McCarthy CM, et al. A paradigm shift in U.S. breast reconstruction: increasing implant rates. Plast Reconstr Surg. 2013;131(1):15–23.
14. Van Hoovels L, Massa B, Stavelin A, De Meyer H, De Schrijver P, Van Laethem V, et al. Analytical performance and user-friendliness of four commercially available point-of-care devices for C-reactive protein. Clin Chim Acta. 2024;560:119737.
15. Fobair P, Stewart SL, Chang S, D'Onofrio C, Banks PJ, Bloom JR. Body image and sexual problems in young women with breast cancer. Psychooncology. 2006;15(7):579–94.
16. Benson AB 3rd, Bekaii-Saab T, Chan E, Chen YJ, Choti MA, Cooper HS, et al. Metastatic colon cancer, version 3.2013: featured updates to the NCCN guidelines. J Natl Compr Canc Netw. 2013;11(2):141–52.
17. Hladiuk M, Huchcroft S, Temple W, Schnurr BI. Arm function after axillary dissection for breast cancer: a pilot study to provide parameter estimates. J Surg Oncol. 1992;50(1):47–52.
18. Kalemikerakis I, Evaggelakou A, Kavga A, Vastardi M, Konstantinidis T, Govina O. Diagnosis, treatment and quality of life in patients with cancer-related lymphedema. J BUON. 2021;26(5):1735–41.
19. Hughes DC, Gorzelitz J, Ortiz A, Cohen L, Parma DL, Boggess T, et al. Impact of six months of three different modalities of exercise on stress in post-treatment breast cancer survivors. Cancers (Basel). 2024;16(19):3398–413.
20. Schulz KF, Grimes DA. Sample size slippages in randomised trials: exclusions and the lost and wayward. Lancet. 2002;359(9308):781–5.
21. Lee KJ, Lee HJ, Lee YJ. Impact of high-intensity circuit resistance exercise on inflammation and immune markers in adult women. Int J Environ Res Public Health. 2022;19(9):5463.
22. Watanabe D, Otani N, Suzuki S, Dohi H, Hirota K, Yonemoto H, et al. Evaluation of VZV-specific cell-mediated immunity in adults with HIV-1 using an IFN-γ release assay. J Med Virol. 2013;85(8):1313–20.
23. Hayashida K, Ozaki T, Nishimura N, Gotoh K, Funahashi K, Nakane K, et al. Evaluation of varicella zoster virus-specific cell-mediated immunity by using an interferon-γ enzyme-linked immunosorbent assay. J Immunol Methods. 2015;426:50–5.
24. Yang P, Chen Z, Zhang J, Li W, Zhu C, Qiu P, et al. Evaluation of varicella-zoster virus-specific cell-mediated immunity by interferon-γ enzyme-linked immunosorbent assay in adults ≥ 50 years of age administered a herpes zoster vaccine. J Med Virol. 2019;91(5):829–35.
25. Lim YA, Kim SS, Cho SW, Cheong JY. Evaluation of the effectiveness of NK Vue Gold Kit in chronic hepatitis B. J Lab Med Qual Assur. 2016;38(3):151–8.

26. Johns I, Moschonas KE, Medina J, Ossei-Gerning N, Kassianos G, Halcox JP. Risk classification in primary prevention of CVD according to QRISK2 and JBS3 ‘heart age’, and prevalence of elevated high-sensitivity C reactive protein in the UK cohort of the EURIKA study. Open Heart. 2018;5(2):e000849.
27. Klassen O, Schmidt ME, Ulrich CM, Schneeweiss A, Potthoff K, Steindorf K, et al. Muscle strength in breast cancer patients receiving different treatment regimes. J Cachexia Sarcopenia Muscle. 2017;8(2):305–16.
28. Patterson RM, Stegink Jansen CW, Hogan HA, Nassif MD. Material properties of Thera-Band® tubing. Phys Ther. 2001;81(8):1437–45.
29. Sakamoto A, Nakagawa H, Nakagawa H, Gamada K. Effect of exercise with a pelvic realignment device on low-back and pelvic girdle pain after childbirth: a randomized control study. J Rehabil Med. 2018;50(10):914–9.
30. Korean Society of Lymphedema. Clinical practice guidelines for exercise management in patients with lymphedema. Seoul: Korean Society of Lymphedema; 2020.
31. Kaelin CM, Coltrera F, Gardiner J, Prouty J. The breast cancer survivor’s fitness plan: a doctor-approved workout plan for a strong body and lifesaving results. New York (NY): McGraw-Hill; 2007.
32. Sharon LK, Refshauge KM, Beith JM, Ward LC, Lee M, Simpson JM, et al. Progressive resistance training and stretching following surgery for breast cancer: study protocol for a randomised controlled trial. BMC Cancer. 2006;6:273.
33. Tetsuya O, Schmitz KH, Ahmed RL, Yoon D. Effects of weight training on quality of life in recent breast cancer survivors: the weight training for breast cancer survivors (WTBS) study. Cancer. 2006;106(9):2076–83.
34. Fairey AS, Courneya KS, Field CJ, Bell GJ, Jones LW, Mackey JR. Randomized controlled trial of exercise and blood immune function in postmenopausal breast cancer survivors. J Appl Physiol. 2005;98(4):1534–40.
35. Hagstrom AD, Marshall PWM, Lonsdale C, Papalia S, Cheema BS, Toben C, et al. The effect of resistance training on markers of immune function and inflammation in previously sedentary women recovering from breast cancer: a randomized controlled trial. Breast Cancer Res Treat. 2016;155(3):471–82.
36. Valenzuela PL, Morales JS, Sanchez-Sanchez J, Lucia A. Exercise training and natural killer cells in cancer survivors: a systematic review and meta-analysis. Int J Environ Res Public Health. 2022;19(9):5463.
37. Pedersen BK, Ullum H. NK cell response to physical activity: possible mechanisms of action. Med Sci Sports Exerc. 1994;26(2):140–6.
38. Blank SE, Johansson JO, Origines MM, Meadows G. Modulation of NK cell activity by moderate intensity endurance training and chronic ethanol consumption. J Appl Physiol. 1992;72(1):8–14.
39. Quintana-Mendias E, Rodríguez-Villalobos JM, Gastelum-Arellanez A, Cervantes N, Carrasco-Legleu CE, Espino-Solis G. The effect of acute physical exercise on natural killer cell populations and

cytokine levels in healthy women. Sports (Basel). 2023;11(10):189.

40. Kasapis C, Thompson PD. The effects of physical activity on serum C-reactive protein and inflammatory markers: a systematic review. J Am Coll Cardiol. 2005;46(10):1563–70.
41. Syvänen K, Korhonen P, Jaatinen P, Vahlberg T, Aarnio P. High-sensitivity C-reactive protein and ankle brachial index in a Finnish cardiovascular risk population. Int J Angiol. 2011;20(1):43–8.
42. Ridker PM, Bassuk SS, Toth PP. C-reactive protein and risk of cardiovascular disease: evidence and clinical application. Curr Atheroscler Rep. 2003;5(5):341–9.
43. Crumley AB, McMillan DC, McKernan M, Going JJ, Shearer CJ, Stuart RC. An elevated C-reactive protein concentration, prior to surgery, predicts poor cancer-specific survival in patients undergoing resection for gastro-oesophageal cancer. Br J Cancer. 2006;94(11):1568–71.
44. Pierce BL, Ballard-Barbash R, Bernstein L, Baumgartner RN, Neuhouser ML, Wener MH, et al. Elevated biomarkers of inflammation are associated with reduced survival among breast cancer patients. J Clin Oncol. 2009;27(21):3437–44.
45. Walsh D, Mahmoud F, Barna B. Assessment of nutritional status and prognosis in advanced cancer: interleukin-6, C-reactive protein, and the prognostic and inflammatory nutritional index. Support Care Cancer. 2003;11(1):60–2.
46. Forrest LM, McMillan DC, McArdle CS, Angerson WJ, Dunlop DJ, Brown DJ. Evaluation of cumulative prognostic scores based on the systemic inflammatory response in patients with inoperable non-small-cell lung cancer. Br J Cancer. 2003;89(6):1028–30.
47. Mattusch F, Dufaux B, Heine O, Martens I, Rost R. Reduction of the plasma concentration of C-reactive protein following nine months of endurance training. Int J Sports Med. 2000;21(1):21–4.
48. Geffken DF, Cushman M, Burke GL, Polak JF, Sakkinen PA, Tracy RP. Association between physical activity and markers of inflammation in a healthy elderly population. Am J Epidemiol. 2001;153(3):242–50.
49. Eric PP, Grandjean PW. Physical activity and high-sensitivity C-reactive protein. Sports Med. 2006;36(5):443–58.
50. Gleeson M, Almey J, Brooks S, Cave R, Lewis A, Griffiths H. Haematological and acute-phase responses associated with delayed-onset muscle soreness in humans. Eur J Appl Physiol Occup Physiol. 1995;71(2–3):137–42.
51. Shim EO, Jang KS, Kim YH. Effects of structured cryotherapy on pain, inflammation, range of motion, and edema in patients with total knee arthroplasty. Iran J Public Health. 2020;49(12):2418–20.
52. Knott EM, Tune JD, Stoll ST, Downey HF. Increased lymphatic flow in the thoracic duct during manipulative intervention. J Am Osteopath Assoc. 2005;105(10):447–56.
53. Dräger S, Kiehne C, Zinser G, Kahle B. Treating cellulitis promptly with compression therapy reduces C-reactive protein levels and symptoms: a randomized-controlled trial. J Dtsch Dermatol Ges. 2025;23:1274–80.

54. Beurskens CHG, van Uden CJT, Strobbe LJA, Oostendorp RAB, Wobbes T. The efficacy of physiotherapy upon shoulder function following axillary dissection in breast cancer: a randomized controlled study. BMC Cancer. 2007;7:166.
55. Lee SA, Kang JY, Kim YD, An AR, Kim SW, Kim YS, et al. Effects of a scapula-oriented shoulder exercise programme on upper limb dysfunction in breast cancer survivors: a randomized controlled pilot trial. Clin Rehabil. 2010;24(7):600–13.
56. Myers JB, Lephart SM, Riemann BL. Sensorimotor contribution to shoulder stability: effect of rehabilitation on dynamic restraint mechanisms. J Athl Train. 2006;41(4):424–36.
57. Park SJ, Kim SH, Kim SH. Effects of thoracic mobilization and extension exercise on thoracic alignment and shoulder function in patients with subacromial impingement syndrome: a randomized controlled pilot study. Healthc (Basel). 2020;8(3):316.

Figures

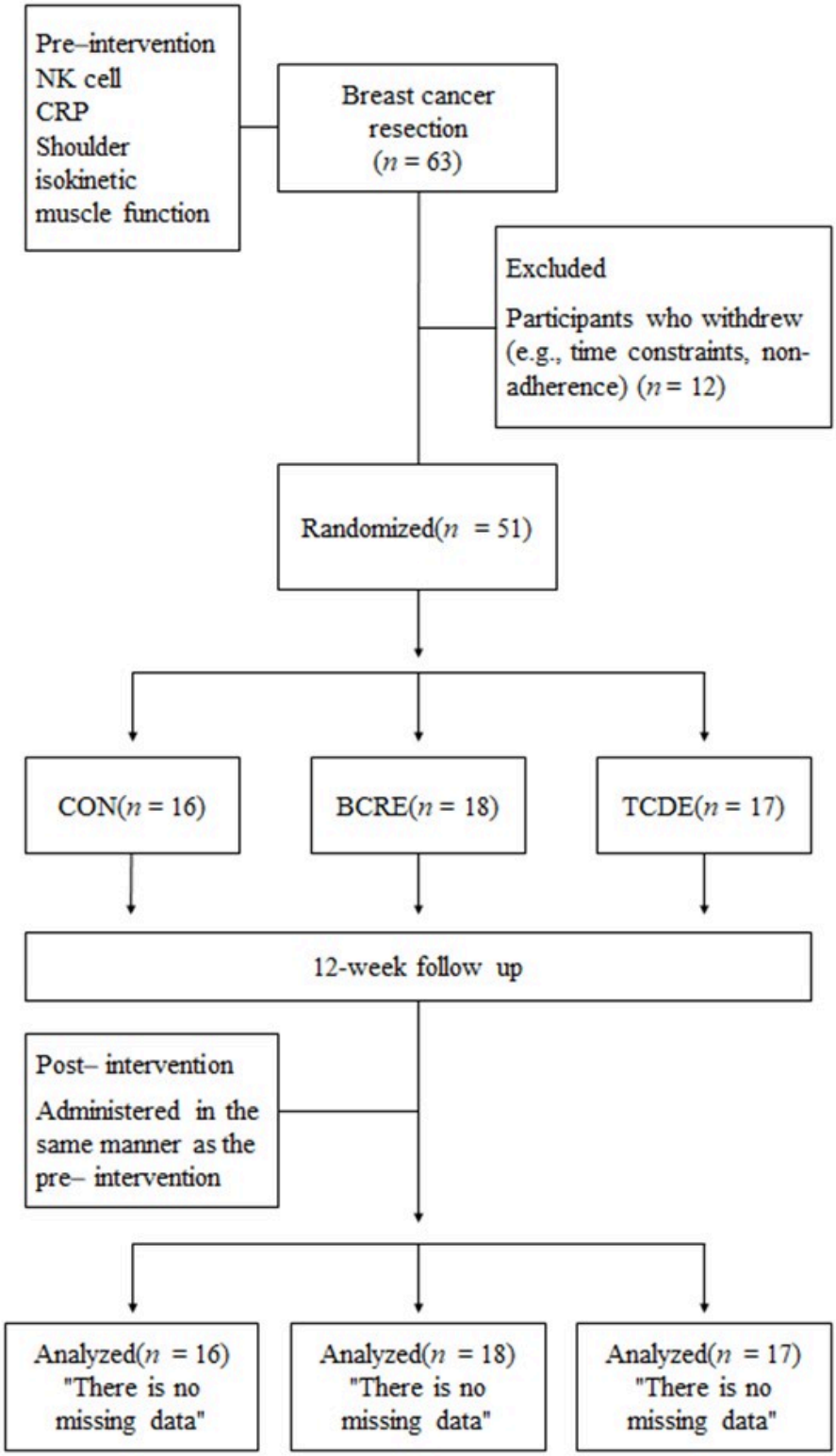


Figure 1

Study flow chart

Flow diagram illustrating the random allocation of participants according to the unified criteria for trial reporting. NK: Natural Killer; CRP: C-reactive protein; CON: control group; BCRE: Breast Cancer Rehabilitation Exercises; TCDE: Thoracic Compression Device Exercise.

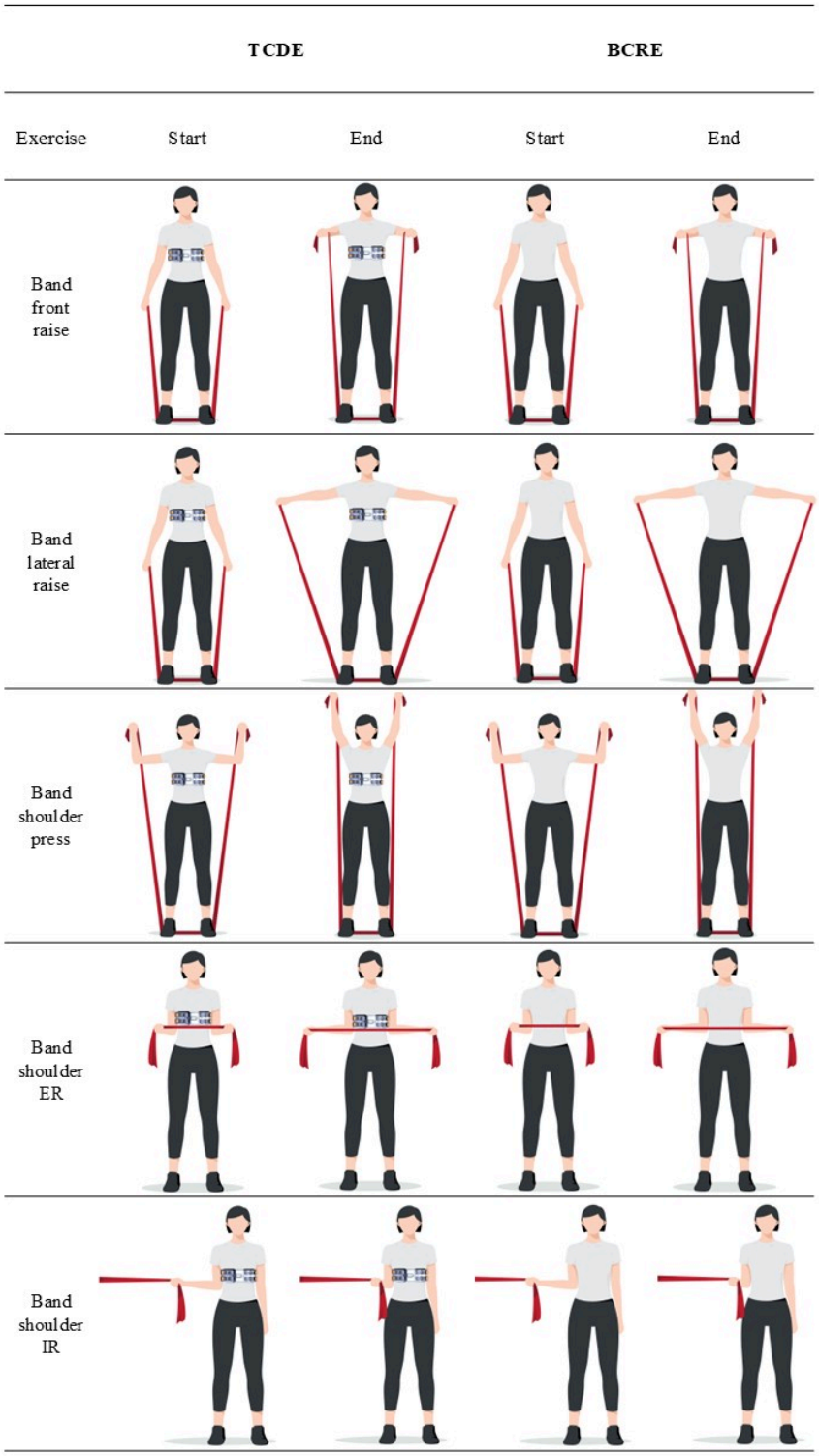


Figure 2

Overview of the TCDE and BCRE programs.

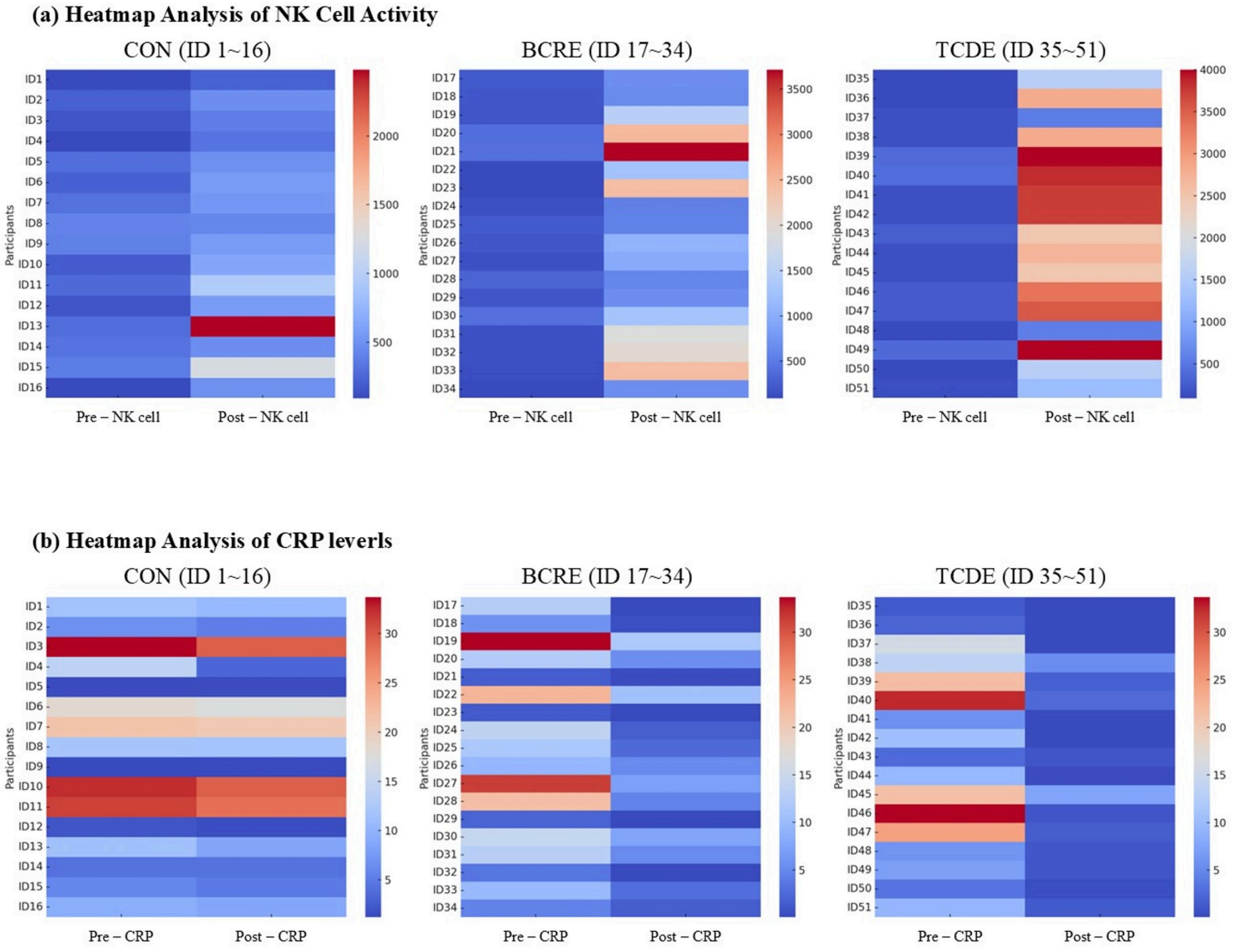


Figure 3

Heatmap Analysis of Changes in NK Cell Activity and C-Reactive Protein Levels Before and After Intervention

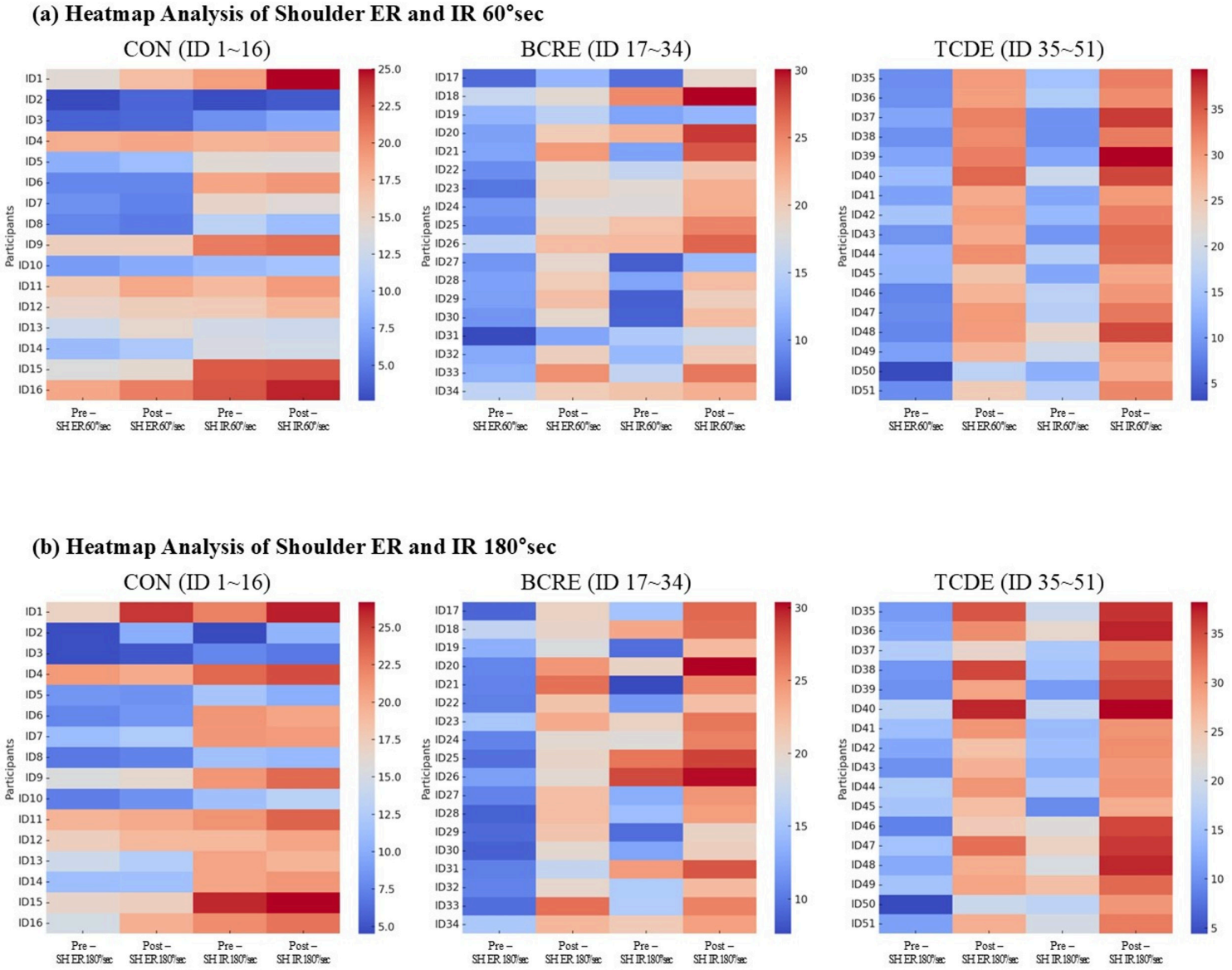


Figure 4

Heatmap Analysis of Changes in Shoulder External and Internal Rotation Strength at 60°/sec and 180°/sec