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RESEARCH

The effect of complex decongestive physiotherapy applied with different compression pressures on skin and subcutaneous tissue thickness in individuals with breast cancer-related lymphedema: a double-blinded randomized comparison trial

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Abstract

Purpose The aim of this study was to evaluate the effect of compression bandage applied with different pressures on the skin and subcutaneous thickness in individuals with breast cancer-related lymphedema (BCRL).

Methods 21 individuals with stage 2 unilateral BCRL participated in the study. Individuals were randomly allocated into two groups as low-pressure bandage (20–30 mmHg) (*n*: 11) and high-pressure bandage (45–55 mmHg) (*n*: 10). Skin and subcutaneous tissue thickness, extremity volume, sleep quality, treatment benefit, and comfort were evaluated by ultrasound from 6 reference points (as hand dorsum, wrist volar, forearm volar, arm volar, forearm dorsum, and arm dorsum), volumetric measurement, Pittsburgh Sleep Quality Index, Patient Benefit Index-Lymphedema, and visual analog scale, respectively. Complex decongestive physiotherapy was applied to both groups. Compression bandage was applied according to their group. Individuals were evaluated at the baseline, 1st session, 10th session, 20th session, and at 3-month follow-up.

Results Skin thickness decreased significantly in the volar reference points of the extremity in the high-pressure bandage group ($p=0.004$, $p=0.031$, and $p=0.003$). Subcutaneous tissue thickness significantly decreased at all reference points in the high-pressure bandage group ($p<0.05$). In the low-pressure bandage group, skin thickness only decreased in the forearm dorsum and the arm dorsum ($p=0.002$, $p=0.035$) and subcutaneous tissue thickness changed for all points ($p<0.05$) except for hand and arm dorsum ($p=0.064$, $p=0.236$). Edema decreased in a shorter time in the high-pressure bandage group ($p<0.001$). No significant differences were found in sleep quality, treatment benefit, and comfort for both groups ($p=0.316$, $p=0.300$, and $p=0.557$, respectively).

Conclusion High pressure was more effective in reducing subcutaneous tissue thickness in the dorsum of hand and arm. The usage of high-pressure can be recommended especially in cases which have edema in the dorsum of hand and arm which is difficult to resolve. Also, high-pressure bandage can provide faster edema resolution and can be used in rapid volume reduction as desired. Treatment outcomes may improve with high-pressure bandage without any impairment in comfort, sleep quality, and treatment benefit.

Trial registration number and date NCT05660590, 12/26/2022 retrospectively registered.

Keywords Breast neoplasm · Compression bandages · Lymphedema · Sleep

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Introduction

Lymphedema (LE) is the common side effect of cancer and cancer treatments [1]. The most common form of lymphedema in western countries is breast cancer-related lymphedema (BCRL). BCRL develops in approximately one out of every five women undergoing breast cancer surgery (BCS) [2]. Axillary lymph node dissection (ALND) and radiotherapy (RT), chemotherapy, post-operative

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seroma, and obesity are important risk factors [3, 4]. Physical and psychosocial symptoms of BRCL such as swelling, heaviness, and tightness/firmness, limited range of motion, and depression can impair activities of daily living and quality of life [5, 6]. Such symptoms also can cause discomfort and sleep disorders [7].

BCRL is not just a disease characterized by edema. Thickening of the skin and subcutaneous adipose tissue is one of its most important features [8, 9]. Decreased lymph flow has been reported to increase lipogenesis and fat storage. The accumulation of substances in the interstitial space causes an increase in the activities of neutrophils, macrophages, and fibroblasts, leading to the development of fibrosis with abnormal collagen deposition in the skin and subcutaneous tissue and an increase in adipose tissue in the subcutaneous tissue [10]. This developing fibroadipose tissue deposition may further disrupt the lymphatic flow [11].

Due to the accumulation of fibroadipose tissue with edema, the skin and subcutaneous tissue of the affected extremity are thicker than the unaffected extremity in individuals with BCRL [12, 13]. It is possible to reduce edema with complex decongestive physiotherapy (CDP), which is accepted as the gold standard in the treatment of lymphedema [14–16]. Compression application with short stretch bandages (non-elastic) is one of the most efficient parts of the CDP [17]. Short stretch bandages are difficult to apply, and the targeted interface bandage pressure is rarely achieved even by specialist healthcare professionals are often used in CDP [18–20]. Furthermore, interface pressure of bandage is an important factor in reducing edema. It is stated that no reduction in edema occurs at pressures below 10 mmHg [17]. However, excessive pressure can cause lymphatic occlusion [17]. As a result, measuring the bandage interface pressure is critical [20]. In studies examining changes in skin and subcutaneous tissue thickness, bandage interface pressures were not assessed [14–16]. In the limited number of studies which assessed bandage interface pressures, skin and subcutaneous tissue thickness were not evaluated [21, 22]. In these studies, treatment periods are short and follow-up evaluations are not available [21, 22]. Moreover, there is no clear agreement exists on how much pressure should be applied with the compression bandage in the BCRL [23].

Considering aforementioned literature gap, the primary aim of the study was to evaluate the effect of different bandage interface pressures with CDP on skin, subcutaneous tissue thickness, and residual volume in different time intervals in individuals with stage 2 BCRL. The secondary aim of the study was to evaluate the effect of different bandage interface pressures with CDP on sleep quality, comfort during the treatment process, and benefit from treatment.

Methods

Study design and participants

The study was planned as a parallel double-blinded randomized comparison trial with data collected at baseline, 1st session, 10th session, 20th session, and 3-month follow-up. This study was carried out between June 2019 and March 2022 at Bolu Abant Izzet Baysal University (Turkey), Faculty of Health Sciences, Department of Physiotherapy and Rehabilitation. 21 individuals with BRCL met the inclusion criteria and participated in the study. Individuals referred by a doctor for the treatment of LE to the Faculty of Health Sciences, Physiotherapy and Rehabilitation Department, were informed about the study. An informed consent form was signed. The inclusion criteria were stage 2 unilateral BCRL according to International Society of Lymphology, involving whole extremity, and to be volunteer. The exclusion criteria were acute deep vein thrombosis, acute soft tissue infection, peripheral artery disease in upper extremity, systemic diseases with peripheral edema (kidney, hearth insufficiency, etc.), allergy to materials used for treatment, mental diseases affecting cooperation, sensory loss, and open wound in the upper limb. This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by Clinical Research Ethics Committee of Bolu Abant Izzet Baysal University, with decision number 2018/175.

Randomization and blinding

An online website (www.sealedenvelop.com) was used for randomization [24]. The randomization list was generated without stratified. Block sizes and list length were defined as 22 and 2 (due to small sample size), respectively. Individuals were randomly allocated (1:1) to two groups, low pressure, and high pressure, according to the list. Patients were blinded to group allocation, and ultrasound (US) assessment was performed by a blinded radiologist.

Interventions

After all the individuals who met the inclusion criteria were distributed into two groups, the individuals were administered CDP, which consists of manual lymph drainage (MLD), skin care, compression bandage, and exercise. The CDP application took about an hour a day. The treatment was planned for 20 sessions for four weeks, five days a week. Individuals were called for follow-up evaluation after three months.

Manual lymph drainage

The individuals participating in the study underwent MLD according to Foeldi technique for approximately 30 min to ensure the entry of interstitial fluid into the lymphatic capillaries and to increase lymph propulsion. The application was started with neck and abdominal drainage. If there are any contraindications for these applications, modified neck and abdominal drainage were performed. The inter-axillar and axillo-inguinal anastomosis pathways were used for drainage of trunk. Then, MLD of the extremity was performed [25].

Skin care

After MLD, skin care was applied to the extremity with a water-based, hypoallergenic, fragrance-free cream. Cicatrizing creams were added to skin care if redness appeared due to compression bandages during the treatment process [25].

Compression bandage

After skin care, a multi-layered bandage was applied to the extremity with short tension compression materials. The stockinet was worn on the extremity. A finger bandage was applied. A pressure gauge with an air-filled pressure transducer probe (Kikuhime, TT Medi Trade, Sorø, Denmark) was used to determine the under-bandage pressure. The device sensor was placed on the dorsal aspect of the wrist, above the stockinet, before applying cotton and bandage. Since a general pressure distribution measurement was desired around the wrist, a large sensor that expanded lateral and medial to the wrist was preferred. Padding was used to protect the extremity and make it cylindrical. Compression bandages were preferred from the same brand to standardize the materials used.

Among the individuals divided into two groups by randomization, compression bandage was applied at 20–30 mmHg pressure to those in the low-pressure bandage group and 45–55 mmHg to those in the high-pressure bandage group. Determination of the pressure groups was based on Damstra et al. [21]'s study. Four to five short stretch bandages were used until the desired pressure was achieved according to the sensor of Kikuhime. The compression bandage application was repeated if the desired pressure could not be achieved. Palpation was used to ensure that the pressure was decreasing upwards. When the compression bandage was finished, the sensor was removed by pulling the cable to which it was attached. The compression bandage stayed on the individual's arm for approximately 23 h.

Exercise

A simple range of motion exercises with multi-layer bandage was recommended [25]. These exercises were "picking apples," elbow flexion and extension, wrist flexion and extension, wrist circumduction, flexion, extension, abduction, and adduction of the fingers. Individuals were told to exercise 2–3 times a day by performing 2–3 sets of 8–10 repetitions for each exercise (Photo. 1).

Outcome measures

Sociodemographic data of the individuals were obtained. Outcome measures included, skin and subcutaneous tissue thickness, residual volume of the extremity, sleep quality, patient benefit from treatment, and patient comfort.

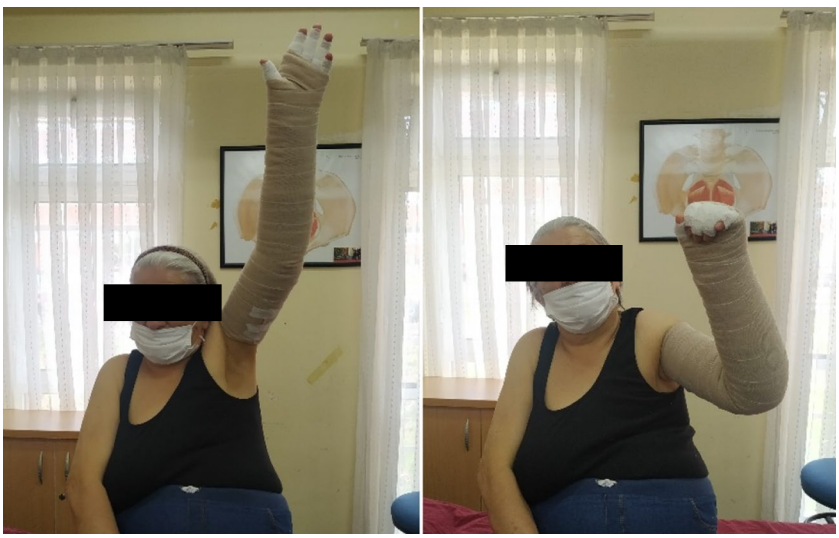

Photo 1 "Picking apples" exercise

Sociodemographic data

The individuals' age, heights, body weights, and body mass indexes were recorded. The affected extremity and the dominant extremity were recorded as right or left. The type of surgery was recorded as lumpectomy and modified radical mastectomy. Whether they received chemotherapy and RT was questioned as yes/no. Lymph node dissection was recorded as ALND or SLNB. The duration of lymphedema was recorded. The stage of the disease was determined according to the consensus of the International Society of Lymphology [26].

Skin and subcutaneous tissue thickness

Evaluation of skin and subcutaneous tissue thickness evaluations via US was performed by a radiologist using a 6–15 MHz linear probe with a LOGIQ US system (GE Healthcare, USA) device. Measurements were made in a sitting position. US gel was applied between the probe and the skin to maximize the transmission of US waves. The US probe was positioned perpendicularly on the skin, and brightness mode (B-mode) images were obtained without applying extra compression to the skin surface. Skin thickness was measured as the distance including the hypoechoic dermis between two thin echogenic lines and recorded in mm, as has been extensively described in previous studies [13]. The subcutaneous tissue distance was noted in mm by measuring the distance between the posterior echogenic line of the dermis and the anterior echogenic line of the muscular fascia [13]. US evaluations were performed bilaterally from six reference points: hand dorsum, volar side of wrist joint, 5 cm below the elbow joint (forearm volar) and 7 cm above (arm volar), 7 cm below the olecranon (forearm dorsum), and 7 cm above olecranon (arm dorsum) [27]. Skin and subcutaneous tissue thickness were evaluated at baseline, 1st session, 10th session, 20th session, and 3-month follow-up.

Residual extremity volume

Extremity volume was determined by the overflowing water method [28]. The volumetric vessel was filled with tap water up to the overflow point of the vessel. Subjects were asked to lean forward and slowly dip their arms into the water until the bar at the base of the volumetric cup snapped between the 2nd and 3rd fingers. During immersion, individuals were asked to avoid movements that could increase the transport of water. The overflow water was calculated by transferring it to the measuring cups and recorded in milliliter. Measurements were made bilaterally. The volumetric measuring cup was emptied and disinfected for the subsequent measurement. Residual extremity volume was calculated in percent with the formula [(affected extremity volume-unaffected extremity volume)/ unaffected extremity volume] × 100. Volumetric measurement has been reported in the literature as the gold standard method used for volume calculation in individuals with LE [28]. Residual extremity volume was evaluated at baseline, 1st session, 10th session, 20th session, and 3-month follow-up.

Sleep quality

Sleep quality was assessed with the Pittsburgh Sleep Quality Index (PSQI). The scale that determines sleep quality consists of 18 questions and evaluates sleep quality in the last four weeks. PSQI has 7 components, and each component is evaluated between 0 and 3 points. The total score ranges from 0 to 21 [29]. A total score higher than 5 indicates poor sleep quality [29]. The subdimensions of PSQI are subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbance, use of sleeping pills, and daytime dysfunction [29]. The Turkish validity and reliability study of the scale was done by Agargun et al. [30]. Sleep quality was evaluated at baseline, 20th session, and 3-month follow-up.

Patient benefit from treatment

The benefit from the treatment was evaluated with the PBI-L. It consists of two five-point Likert-type questionnaires containing the same 23 questions, the PBI-L Patient Needs Questionnaire, and the Patient Benefit Questionnaire. The individual's benefit from the treatment is scored between 0 and 4. "0" indicates no benefit; "4" indicates that the patient has received maximum benefit [31]. Turkish validity and reliability of PBI-L were made by Duygu et al. [32]. Subjective benefit from treatment was evaluated at the end of the 20th session.

Patient comfort

Patient comfort was evaluated with Visual Analogue Scale at the end of the treatment. It was explained to the individual that 0 point of a 10-cm line represents minimum comfort and 10 points represents maximum comfort. The individual was asked to mark the level of comfort they perceived during the treatment. The point marked by the individual was measured with a ruler and recorded in cm [33]. Comfort was evaluated at the end of the 20th session.

Analysis of data

For descriptive statistics, mean and standard deviation or median and minimum–maximum values were given in numerical variables. Categorical variables were defined by number and percentage. The assumption of normality

was analyzed using the Shapiro-Wilks test and graphs (histogram, QQ plot, etc.). In comparing the two groups, the *t*-test was used for independent groups when the assumptions were met, and the Mann–Whitney *U* test was used when the assumptions were not met. Considering the small number of individuals in the groups, non-parametric tests were preferred for in-group comparisons. Wilcoxon's test or Friedman's test was used to examine the time change. Paired comparison (post-hoc) tests were used to determine the group that made the difference. Chi-square tests were used to examine whether there was a significant difference between categorical variables. There are no post-power calculation methods in the programs for non-parametric methods; the calculations were obtained by parametric test methods according to the subcutaneous thickness values of the forearm volar. When the alpha margin of error was accepted as 5%, the post hoc power of the study was 88.3%. Calculations were made with PASS 11 and SPSS v.26 package programs. Significance level was taken as $p < 0.05$.

Results

Flow chart of the study was given in Fig. 1.

The physical and sociodemographic characteristics of the individuals in the low- and high-pressure groups were

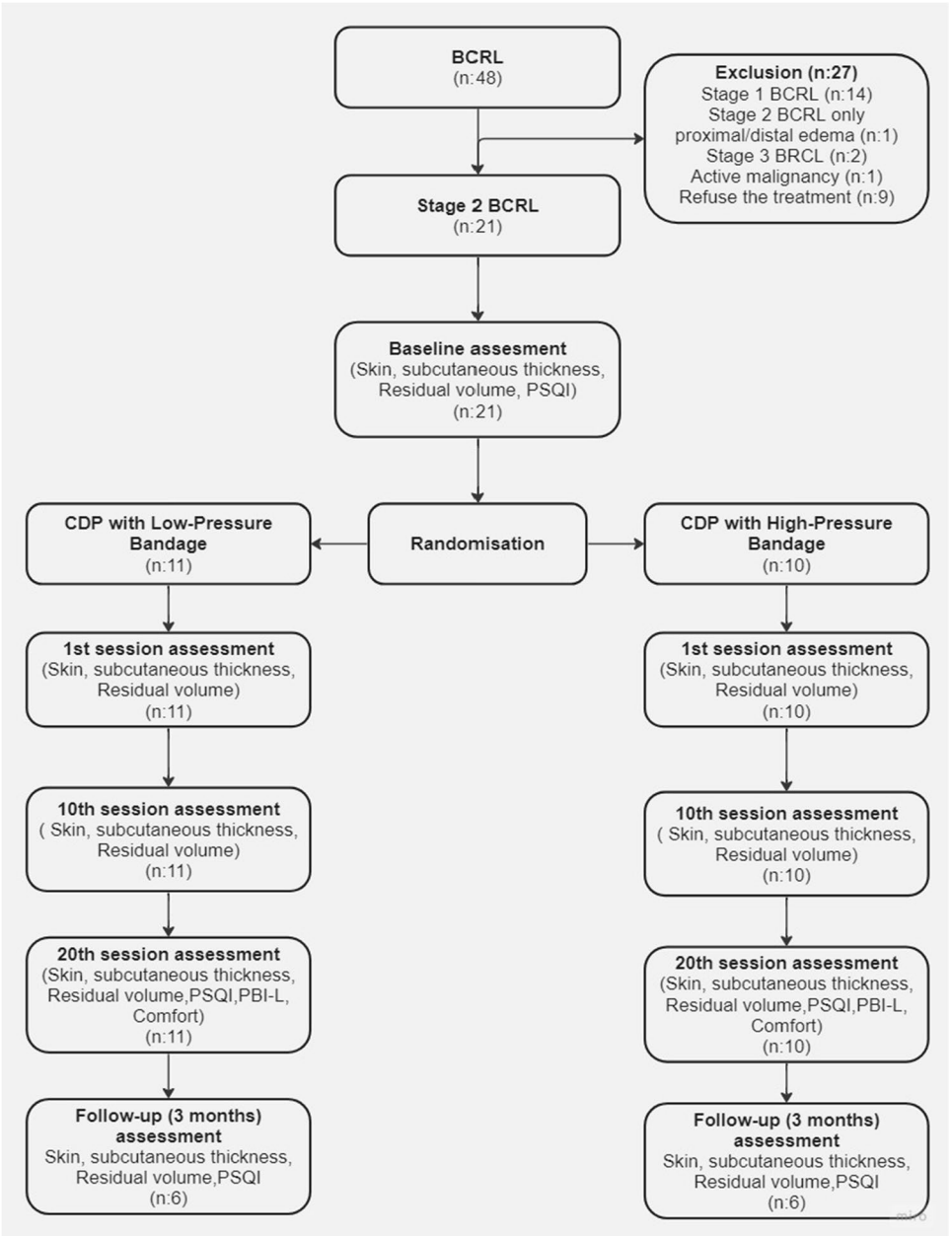

Fig. 1 Flow chart. BCRL, breast cancer-related lymphedema; CDP, complex decongestive physiotherapy; PSQI, Pittsburg Sleep Quality Index; PBI-L, Patient Benefit Index-Lymphedema

similar ($p > 0.05$) (Table 1). The skin and subcutaneous tissue thickness of the affected extremities was similar in both groups, and the skin and subcutaneous tissue thickness of the unaffected extremities was also similar ($p > 0.05$) (Table 2).

At the baseline, in the low-pressure group, the skin thickness of the affected extremity was significantly greater than that of the unaffected extremity at all reference points ($p = 0.005$, $p = 0.024$, $p = 0.012$, $p = 0.010$, $p = 0.003$, and $p = 0.008$, respectively). At the baseline, in the high-pressure group, the skin thickness of the affected extremity was significantly greater than that of the unaffected extremity at all reference points ($p = 0.012$ $p = 0.008$, $p = 0.008$, $p = 0.008$, and $p = 0.008$, respectively) except the forearm volar ($p = 0.066$). At the baseline, the subcutaneous tissue thickness of the affected extremities in both groups was thicker than that of the unaffected extremities at all reference points ($p < 0.05$) (Table 2).

Skin thickness on the dorsum of the hand did not change in both groups at the end of the 20th session ($p = 0.084$ and $p = 0.124$, respectively). In the low-pressure group, skin thickness on the dorsum of the forearm and arm decreased significantly at the end of the 20th session ($p = 0.002$ and $p = 0.035$, respectively). In the high-pressure group, the skin thickness on the wrist volar, forearm volar, and arm volar decreased significantly ($p = 0.004$, $p = 0.031$, and $p = 0.003$, respectively) (Table 3).

In the low-pressure group, subcutaneous tissue thickness was significantly decreased at all reference points except the dorsum of the hand and arm ($p = 0.012$, $p = 0.008$, $p = 0.001$, $p = 0.003$, $p = 0.064$, and $p = 0.236$, respectively). In the high-pressure group, subcutaneous tissue thickness was decreased at all reference points ($p = 0.039$, $p = 0.001$, $p = 0.006$, $p = 0.023$, $p < 0.001$, and $p = 0.002$, respectively) (Table 4).

At the baseline, residual extremity volume was similar in the low- and high-pressure groups ($p = 0.13$). There was a significant decrease in residual extremity volume in both groups ($p = 00$ 0.003 and $p = 0.001$, respectively). In the low-pressure group, residual volume was significantly decreased between the baseline and 20th session and between baseline and follow-up. In the high-pressure group, residual volume was significantly decreased between the baseline and 10th sessions and between the baseline and 20th sessions (Table 5).

Table 1 Physical and sociodemographic features of individuals

		Low bandage pressure ($n = 11$) $X \pm SS$	High bandage pressure ($n = 10$) $X \pm SS$	p
Age (year)		61.18 ± 8.87 (Min: 48–Max: 74)	66.3 ± 12.16 (Min: 49–Max: 80)	0.281§
Body height (m)		1.59 ± 0.06 (Min: 1.5–Max: 1.7)	1.59 ± 0.06 (Min: 1.49–Max: 1.68)	0.914§
Body weight (kg)		71.0 ± 8.89 (Min: 56–Max: 88)	79.8 ± 10.69 (Min: 61–Max: 93)	0.054§
BMI (kg/m^2)		28.07 ± 3.65 (Min: 21.08–Max: 34.38)	31.66 ± 3.65 (Min: 24.13–Max: 38.29)	0.055§
BCRL duration		4.09 ± 2.39 (Min: 1–Max: 8)	3.40 ± 2.17 (Min: 1–Max: 7)	0.498§
		n (%)	*n* (%)	
Affected extremity	Right Left	4 (36.4) 7 (63.6)	4 (40.0) 6 (60.0)	1.000§§
Dominant extremity	Right Left	10 (90.9) 1 (9.1)	8 (80.0) 2 (20.0)	0.586§§
Cancer surgery	MRM LUM	7 (63.6) 4 (36.4)	6 (60.0) 4 (40.0)	1.000§§
LNE	ALND SLNB	8 (72.7) 3 (27.3)	10 (100.0) 0 (0.0)	0.214§§
RT	Yes No	9 (81.8) 2 (18.2)	6 (60.0) 4 (40.0)	0.361§§
KT	Yes No	11 (100.0) 0 (0.0)	7 (70.0) 3 (30.0)	0.090§§

BMI body mass index, *BCRL* breast cancer-related lymphedema, *LNE* lymph node excision, *ALND* axillar lymph node dissection, *SLNB* sentinel lymph node biopsy, *MRM* modified radical mastectomy, *LUM* lumpectomy, *RT* radiotherapy, *KT* chemotherapy

§*t*-test in independent groups

§§Chi-squared test

*$p \leq 0.05$

Table 2 Skin and subcutaneous tissue thickness assessment in groups and between groups

Reference points		Low bandage pressure ($n=11$)	High bandage pressure ($n=10$)	$p^{\S}$	Low bandage pressure ($n=11$)	High bandage pressure ($n=10$)	$p^{\S}$
		Skin thickness (mm)			Subcutaneous thickness (mm)		
Hand dorsum	Unaffected	0.80 (0.6–0.8)	0.80 (0.6–1.0)	0.314	1.70 (1.3–3.2)	1.85 (1.0–4.2)	1.000
	Affected	0.90 (0.8–1.6)	1.15 (0.7–1.8)	0.349	4.60 (2.2–7.4)	8.90 (1.6–12.9)	0.197
	$p^{\S\S}$	0.005*	0.012*		0.003*	0.007*	
Wrist volar	Unaffected	0.80 ± 0.10	0.75 ± 0.13	0.326	3.50 (1.7–7.2)	2.4 (1.5–7.2)	0.251
	Affected	1.1 (0.6–2.5)	1.2 (0.8–2.4)	0.756	10.5 (5.2–30.1)	9.3 (4.0–26.8)	0.654
	$p^{\S\S}$	0.024*	0.008*		0.003*	0.005*	
Forearm volar	Unaffected	0.80 (0.6–1.0)	0.85 (0.7–1.7)	0.173	4.3 (2.5–12.3)	4.0 (2.3–9.5)	0.605
	Affected	1.0 (0.6–2.9)	1.2 (0.7–3.2)	0.314	9.2 (3.9–31.5)	7.7 (3.5–28.9)	0.918
	$p^{\S\S}$	0.012*	0.066		0.013*	0.005*	
Arm volar	Unaffected	0.7 (0.6–0.9)	0.85 (0.6–1.1)	0.314	4.2 (2.2–8.4)	5.1 (2.1–8.6)	0.223
	Affected	1.0 (0.7–3.2)	1.45 (0.8–3.2)	0.152	6.1 (3.1–33.4)	7.75 (4.5–27.6)	0.282
	$p^{\S\S}$	0.010*	0.008*		0.004*	0.007*	
Forearm dorsum	Unaffected	0.9 (0.5–1.2)	0.9 (0.6–1.4)	0.468	4.9 (2.4–6.5)	3.15 (1.6–9.3)	0.223
	Affected	1.5 (1.0–3.2)	1.70 (0.5–3.6)	0.349	11.3 (2.5–20.1)	13.0 (15.6–24.9)	0.387
	$p^{\S\S}$	0.003*	0.008*		0.003*	0.005*	
Arm dorsum	Unaffected	1.0 (0.6–1.3)	0.80 (0.5–6.2)	0.468	7.4 (3.5–16.5)	6.5 (3.8–10.8)	0.973
	Affected	1.5 (0.7–2.9)	1.65 (0.6–6.8)	0.557	13.0 (4.9–36.0)	13.05 (6.8–25.3)	0.918
	$p^{\S\S}$	0.008*	0.008*		0.003*	0.005*	

[§]Mann–Whitney *U* test

[§§]Wilcoxon's test

*$p \leq 0.05$

PSQI total score and subscale scores were similar in the low- and high-pressure groups at the baseline ($p > 0.05$). At the end of the 20th session, there was no significant change in PSQI total score and subscale scores in both groups ($p > 0.05$). PSQI total score decreased significantly in the low-pressure group between the 20th session and follow-up ($p = 0.036$) (Table 6).

There was no significant difference in PBI-L scores and comfort score between the groups at the 20th session ($p = 0.300$ and $p = 0.557$, respectively).

Adverse events and harms

Two individuals in the high-pressure bandage group developed redness on the radial side of the wrist joint. The tissue was supported with extra cotton and cicatrizing creams; further tissue damage was prevented. In the low bandage group, an individual with urticaria due to a side effect of a medication experienced an increase in the severity of urticaria due to the bandage. Treatment was continued with an itch-reducing lotion recommended by the physician. No circulatory complications were observed in the individuals.

Discussion

In this study, compression bandages with different pressures were compared; it was shown that low-pressure bandage was effective in reducing skin thicknesses dorsal sides, excluding the hand. It was showed that high-pressure bandage was effective in reducing skin thickness at reference points on the volar sides. In addition, high-pressure bandage was found to be effective in reducing the subcutaneous thickness in the dorsum of the hand and arm and in reducing the residual limb volume in a shorter time. It was observed that sleep quality did not change depending on the bandage pressure in both groups. The benefit from the treatment and the comfort of the individuals during the treatment were similar in both groups.

In the literature, skin and subcutaneous tissue thickening have been reported frequently in BCRL [12, 13, 27, 34]. This is not surprising, as the skin, and especially the subcutaneous tissue, is the main site of edema accumulation [12]. An increase in thickness is associated with edema and fibroadipose tissue deposition in LE. Skin and subcutaneous thickness decrease after CDP [16, 35, 36]. Similar to the literature, skin and subcutaneous tissue thickness decreased after CDP in our study. It is thought

Table 3 Skin thickness assessment in different sessions

Reference points	Low bandage pressure ($n=11$)	High bandage pressure ($n=10$)	$p^{\S}$
Hand dorsum			
Baseline	0.90 (0.8–1.6)	1.15 (0.7–1.8)	0.349
1st session	0.80 (0.5–1.3)	0.95 (0.6–1.1)	0.468
10th session	0.70 (0.6–1.0)	0.85 (0.6–1.1)	0.132
20th session	0.70 (0.7–0.9)	0.80 (0.6–1.1)	0.557
Follow-up	0.70 (0.6–0.9)	0.75 (0.6–1.0)	0.310
$p^{\S\S}$	0.084	0.124	
Wrist volar			
Baseline	1.1 (0.6–2.5)	1.2 (0.8–2.4)^{a}	0.756
1st session	0.80 (0.7–1.6)	0.95 (0.8–2.2)^{ab}	0.132
10th session	0.80 (0.6–1.0)	0.90 (0.6–2.1)^{ab}	0.468
20th session	0.80 (0.6–1.0)	0.80 (0.5–1.5)^{ab}	1.000
Follow-up	0.70 (0.7–1.0)	0.65 (0.5–1.6)^{b}	0.485
$p^{\S\S}$	0.527	0.004*	
Forearm volar			
Baseline	1.0 (0.6–2.9)	1.2 (0.7–3.2)^{a}	0.314
1st session	1.0 (0.9–1.5)	0.95 (0.7–1.7)^{ab}	0.973
10th session	0.80 (0.6–1.1)	0.85 (0.5–1.5)^{b}	1.000
20th session	0.80 (0.7–1.2)	0.80 (0.5–1.8)^{ab}	0.918
Follow-up	0.90 (0.7–1.2)	0.85 (0.7–1.8)^{ab}	0.818
$p^{\S\S}$	0.809	0.031*	
Arm volar			
Baseline	1.0 (0.7–3.2)	1.45 (0.8–3.2)^{a}	0.152
1st session	1.0 (0.7–1.5)	1.15 (0.7–1.7)^{ab}	0.197
10th session	0.80 (0.5–1.4)	0.90 (0.6–1.7)^{ab}	0.512
20th session	0.80 (0.6–1.5)	0.80 (0.4–1.7)^{b}	0.863
Follow-up	0.90 (0.7–1.3)	0.90 (0.7–1.2)^{b}	0.818
$p^{\S\S}$	0.596	0.003*	
Forearm dorsum			
Baseline	1.5 (1.0–3.2)^{a}	1.70 (0.5–3.6)	0.349
1st session	1.3 (0.7–1.6)^{ab}	1.10 (0.6–3.1)	0.918
10th session	0.9 (0.5–1.5)^{b}	1.00 (0.7–2.3)	0.314
20th session	0.9 (0.6–9.0)^{ab}	0.90 (0.7–2.6)	0.605
Follow-up	0.95 (0.7–1.4)^{ab}	0.85 (0.7–2.7)	0.818
$p^{\S\S}$	0.002*	0.162	
Arm dorsum			
Baseline	1.5 (0.7–2.9)^{a}	1.65 (0.6–6.8)	0.557
1st session	1.3 (0.8–2.1)^{ab}	1.35 (0.7–7.1)	0.863
10th session	1.0 (0.8–1.9)^{b}	1.25 (0.5–8.8)	0.314
20th session	1.1 (0.6–1.8)^{ab}	1.15 (0.6–8.7)	0.863
Follow-up	1.05 (0.8–1.6)^{ab}	1.10 (0.9–2.6)	0.699
$p^{\S\S}$	0.035*	0.113	

§Mann–Whitney *U* test

§§Friedman's test

*$p \leq 0.05$. The use of superscript different letters indicates statistical difference

Table 4 Subcutaneous tissue thickness assessment in different sessions

Reference points	Low bandage pressure ($n=11$)	High bandage pressure ($n=10$)	$p^{\S}$
Hand dorsum			
Baseline	4.6 (2.2–7.4)	8.9 (1.6–12.9)^{a}	0.197
1st session	3.5 (1.5–6.8)	6.55 (1.4–11.9)^{ab}	0.173
10th session	3.3 (1.6–6.5)	3.75 (1.2–9.1)^{b}	0.557
20th session	3.2 (1.7–6.5)	3.65 (1.1–9.0)^{b}	0.605
Follow-up	3.55 (1.6–5.3)	5.6 (1.1–8.5)^{ab}	0.589
$p^{\S\S}$	0.064	0.039*	
Wrist volar			
Baseline	10.5 (5.2–30.1)^{a}	9.3 (4.0–26.8)^{a}	0.654
1st session	5.7 (3.2–20.8)^{ab}	5.7 (2.9–22.7)^{ab}	0.756
10th session	4.8 (1.8–9.7)^{b}	3.75 (2.5–10.5)^{ab}	0.654
20th session	5.0 (1.8–7.5)^{ab}	3.0 (2.5–7.9)^{b}	0.197
Follow-up	4.5 (1.6–7.6)^{ab}	4.4 (1.6–8.9)^{ab}	0.818
$p^{\S\S}$	0.012*	0.001*	
Forearm volar			
Baseline	9.2 (3.9–31.5)^{a}	7.7 (3.5–28.9)^{a}	0.918
1st session	6.9 (1.9–14.7)^{ab}	5.15 (3.1–20.0)^{ab}	0.314
10th session	5.9 (2.4–10.2)^{ab}	4.55 (2.6–9.0)^{ab}	0.557
20th session	3.8 (1.9–8.6)^{b}	4.5 (2.4–6.5)^{b}	1.000
Follow-up	4.55 (2.5–6.6)^{b}	4.9 (4.1–7.3)^{ab}	0.589
$p^{\S\S}$	0.008*	0.006*	
Arm volar			
Baseline	6.1 (3.1–33.5)^{a}	7.75 (4.5–27.6)^{a}	0.282
1st session	6.0 (2.8–55.5)^{ab}	5.4 (3.4–17.7)^{ab}	0.809
10th session	5.1 (2.6–11.7)^{ab}	5.65 (3.5–10.7)^{ab}	0.605
20th session	4.9 (2.4–7.3)^{b}	4.4 (2.3–7.3)^{b}	0.705
Follow-up	5.3 (2.3–8.7)^{b}	5.25 (4.1–7.2)^{ab}	0.937
$p^{\S\S}$	0.001*	0.023*	
Forearm dorsum			
Baseline	11.3 (2.5–20.1)^{a}	13.0 (9.3–24.9)^{a}	0.387
1st session	8.5 (2.3–21.6)^{ab}	10.15 (4.8–20.5)^{ab}	0.468
10th session	5.7 (2.3–11.3)^{ab}	5.85 (4.1–16.5)^{b}	0.809
20th session	6.3 (2.3–9.2)^{b}	6.4 (2.9–13.8)^{b}	0.512
Follow-up	7.35 (6.0–12.8)^{ab}	7.95 (2.5–16.7)^{ab}	0.937
$p^{\S\S}$	0.003*	< 0.001*	
Arm dorsum			
Baseline	13.0 (4.9–36.0)	13.05 (6.8–25.3)^{a}	0.918
1st session	10.9 (4.4–24.8)	11.35 (4.9–23.9)^{ab}	0.809
10th session	10.3 (4.3–15.7)	9.4 (7.0–18.0)^{ab}	0.809
20th session	9.1 (4.0–15.5)	9.2 (5.1–15.4)^{b}	0.756
Follow-up	7.8 (5.7–24.0)	9.05 (5.8–19.3)^{ab}	0.818
$p^{\S\S}$	0.236	0.002*	

The use of superscript different letters indicates statistical difference

§Mann–Whitney *U* test

§§Friedman's test

*$p \leq 0.05$

Table 5 Residual volume assessment in different sessions

Assessment sessions	Residual volume (%)		
	Low bandage pressure ($n=11$)	High bandage pressure ($n=10$)	$p^{\S}$
Baseline	36.4 (15.6–72.8)[ab]	45 (25.47–104.4)[ab]	0.13
1st session	28 (11.7–71.1)[ab]	34.5 (15.6–63.5)[ab]	0.48
10th session	13.7 (10.1–56.3)[ab]	29.52 (8.4–38.3)[a]	0.52
20th session	14 (8.2–56.3)[a]	27.5 (3–35.1)[b]	0.48
Follow-up	21.6 (1.4–35)[b]	31.4 (12.4–62.3)[ab]	0.55
$p^{\S\S\S}$	0.003*	0.001*	

The use of superscript different letters indicates statistical difference

[§]Mann–Whitney *U* test

[§§§]Friedman's test

*$p \leq 0.05$

that the decrease in skin and subcutaneous tissue thickness was due to decreased edema in the tissue.

In this study, the effect of compression bandage applied with low and high pressures on skin thickness in different regions was different. High bandage pressure was effective on the volar side of the extremity skin; low bandage pressure was effective on the dorsal side of the extremity skin except hand. Any information was not found in the literature to support or contradict our data. This situation may also be coincidental. Studies are needed in this regard.

When the effect of different bandage pressures on the subcutaneous tissue was examined, it was found that high pressure bandage reduced the subcutaneous tissue thickness at all reference points, while low pressure bandage was effective in reducing the subcutaneous tissue thickness at the reference points except the dorsum of the hand and the dorsum of the arm. The anatomical shape of the hand was thought to be the reason why high pressure was effective in the reduction of edema in the dorsum of the hand. Due to its flatter structure compared to the forearm and arm, the compression bandage applies less homogeneous pressure compared to cylindrical areas such as the arm and forearm. Bandage pressure tends to be greater where the curvature of the extremities is greater and less where the curvature is less [37]. In this case, the pressure on the dorsum of the hand may be lower than on the ulnar and radial parts. It was thought that the bandage applied with high pressure creates a pressure that is sufficient to reduce the edema on the hand compared to the low pressure, as it increases the pressure on the dorsum as well as the sides of the hand.

The number of studies comparing the effect of different compression pressures on extremity volume or circumference in individuals with BCRL is limited. Damstra et al. [21] tested low (20–30 mmHg) and high (44–58 mmHg) bandage interface pressures in 36 individuals with stage 2 BCRL. They evaluated the decrease in arm volume after 2 h and 24 h. It was stated that the decrease in the low-pressure bandage group at the end of 24 h was as much as the high-pressure bandage group. They supported this finding with research showing that the continuity of lymph flow in a healthy person could reach 49 mmHg but dropped to 24 mmHg in BCRL [38, 39]. Based on this, it was stated that high compression may have blocked the lymph flow. However, Belgrado et al. [40] reported that the occlusion in the superficial lymphatic vessels was around 82 mmHg on average. Mosti and Cavazzi [17] stated that the decrease in transmission due to lymphatic occlusion occurs with a pressure of 60 mmHg. Furthermore, Karafa et al. [22] compared the edema effect of 3 different bandage pressures, 20–30 mmHg, 30–40 mmHg, and 41–60 mmHg, in individuals with BCRL before treatment, on the 1st day, 7th day, and 14th day. They reported that bandages applied with 30–40 mmHg and 41–60 mmHg were more effective in reducing edema than those applied with 20–30 mmHg pressure. In this study, it was observed that low- and high-pressure bandages were equally effective based on arm volume. Although the low-pressure range was determined as 20–30 mmHg, in this study, the bandage was usually applied very close or equal to the upper limit. For this reason, it was thought that the results of the two groups were similar.

There was a difference in edema reduction between the two groups over the course of treatment when residual volume was considered. Based on our findings, it can be interpreted that high pressure bandage reduces edema in a shorter time. However, reduction in soft tissue thickness at most reference points and volume reduction in low pressure bandage group was between pre-treatment and post-treatment. Moffat et al. [41] stated that reductions in extremity volume could continue in a 4-week CDP program compared to a 2-week CDP program in their study investigating the factors affecting the reduction in extremity volume of CDP. Their findings may be supported by low bandage pressure group of this study.

Table 6 Sleep quality assessment in different sessions

Pittsburgh Sleep Quality Index	Low bandage pressure ($n=11$)	High bandage pressure ($n=10$)	$p^{\S}$
Subjective sleep quality			
Baseline	1.0 (0.0–2.0)	1.0 (0.0–2.0)	0.637
20th session	1.0 (1.0–2.0)	1.0 (0.0–2.0)	0.354
Follow-up	1.0 (0.0–2.0)	1.0 (1.0–2.0)	0.206
$p^{\S\S}$	0.174	0.717	
Sleep latency			
Baseline	1.0 (0.0–3.0)	1.5 (0.0–2.0)	0.344
20th session	1.0 (0.0–2.0)	2.0 (1.0–2.0)	0.099
Follow-up	1.0 (0.0–2.0)	2.0 (0.0–2.0)	0.297
$p^{\S\S}$	0.779	0.584	
Sleep duration			
Baseline	0.0 (0.0–2.0)	0.5 (0.0–1.0)	0.201
20th session	0.0 (0.0–2.0)	0.5 (0.0–2.0)	0.063
Follow-up	0.0 (0.0–0.0)	0.5 (0.0–1.0)	0.056
$p^{\S\S}$	0.223	0.807	
Habitual sleep efficiency			
Baseline	0.0 (0.0–3.0)	1.0 (0.0–3.0)	0.657
20th session	1.0 (0.0–3.0)	3.0 (0.0–3.0)	0.332
Follow-up	1.5 (0.0–3.0)	3.0 (0.0–3.0)	0.411
$p^{\S\S}$	0.368	0.247	
Sleep disturbances			
Baseline	1.0 (1.0–3.0)	1.5 (0.0–2.0)	0.390
20th session	1.0 (1.0–3.0)	1.0 (1.0–2.0)	1.000
Follow-up	1.0 (0.0–2.0)	1.5 (0.0–2.0)	0.932
$p^{\S\S}$	0.368	0.584	
Use of sleeping medication			
Baseline	0.0 (0.0–0.0)	0.0 (0.0–3.0)	0.294
20th session	0.0 (0.0–1.0)	0.0 (0.0–3.0)	0.890
Follow-up	0.0 (0.0–0.0)	0.0 (0.0–3.0)	0.140
$p^{\S\S}$	1.000	0.368	
Daytime dysfunction			
Baseline	0.0 (0.0–2.0)	0.0 (0.0–2.0)	0.799
20th session	1.0 (0.0–2.0)	0.0 (0.0–2.0)	0.143
Follow-up	0.0 (0.0–1.0)	0.0 (0.0–1.0)	1.000
$p_{\S\S}$	0.097	0.368	
Total score			
Baseline	4.0 (2.0–14.0); 2.08[ab]	5.5 (2.0–13.0)	0.663
20th session	5.0 (3.0–13.0); 2.67[a]	7.5 (3.0–13.0)	0.316
Follow-up	4.0 (0.0–10.0); 1.25[b]	8.0 (3.0–13.0)	0.199
$p^{\S\S}$	0.036*	0.494	

The use of superscript different letters indicates statistical difference

[§]Mann–Whitney *U* test

[§§]Friedman's test

*$p \leq 0.05$

One of the important results of this study was related to sleep quality. BCRL is one of the long-term risk factors that cause sleep quality deterioration after BCS [42]. Individuals with BCRL have atypical sleep disorders. Situations such as elevation by placing a pillow under the affected arm and not being able to change position while sleeping negatively affect sleep quality [43]. Physical problems caused by BCRL, such as pain and numbness, cause sleep disturbances. [44]. Tamam et al. [45] stated that individuals with stage 2 BCRL had sleep disorder. Similar to the literature, it was determined that individuals in the high-pressure bandage group had sleep disorders at the beginning of the treatment. It was observed that the low bandage group was close to the sleep disorder limit before the treatment. Considering that the bandage applied with high pressures may cause sleep disturbance due to discomfort, sleep evaluation was performed. However, both groups had no difference in sleep disturbance and after treatment. To our knowledge no study was found in the literature on the effect of CDP on sleep quality in individuals with BCRL. There was a decrease in sleep disturbance in the low bandage group between post-treatment and follow-up. It was thought that there might be different personal, psychological, or familial factors that could affect sleep quality during this three-month period.

An important assessment used in outcome measures of lymphedema treatment is the subjective benefit gained from treatment from the patient's perspective. The subjective benefit from LE treatment is usually assessed by individual-filled quality of life questionnaires. However, the quality of life questionnaires also includes factors that are not related to treatment but may affect the results of the questionnaire [31]. PBI-L was used in our study to eliminate these factors and to evaluate the benefit of direct treatment. The perceived benefit from treatment in the two groups in our study was similar. To the best of our knowledge, there was no study in the literature that could compare the benefit of treatment in BCRL.

Another patient perspective assessment that this study addressed was comfort. In this study, individuals bandaged with low and high pressures had similar comfort during the treatment process. Damstra et al. [21] stated that the comfort of the group was bandaged with 20–30 mmHg pressure was better than that of the other group (45–58 mmHg pressure). Karafa et al. [22] evaluated three different bandage pressures and pain in individuals with BCRL, and the pain was highest in the bandage group with 20–30 mmHg, followed by the bandage group with 41–60 mmHg and 30–40 mmHg. Medium pressure has been noted to be best tolerated. It has been reported that in the group that was bandaged with a pressure of 20–30 mmHg, skin irritation occurred due to the slipping and gathering of the bandage, and this reduced the patient's comfort [22]. Since the bandage was mostly applied close to the upper limit of the low-pressure range in our study, no slippage or accumulation was observed in the bandage applications.

Limitations

Few studies in the literature have evaluated the efficacy of CDP in a randomized double-blind trial. This study also contributes to the literature in that it includes both the follow-up process and different and wide time intervals. Nevertheless, there were several limitations in this study. Since there is only one Kikuhime pressure sensor, only the pressure at the wrist could be measured. Pressure gradient was checked by palpation. Absence of another pressure sensor for proximal forearm was one of the limitations of the study. Since the study coincided with the COVID-19 pandemic period, individuals disturbed by the symptoms of BCRL were willing to seek treatment in some way, but nearly half of the individuals avoid coming to the follow-up evaluations. This made it difficult for us to evaluate the follow-up results. Lastly, it was thought that fibrosis in the tissue was also effective in the reduction of edema, but fibrosis in the tissue could not be evaluated.

Conclusions

For edema localized on the dorsum of the hand and arm, a high-pressure compression bandage can be used with sufficient cotton or sponge applications. If edema is desired to be removed from the extremity in a shorter time, a high-pressure compression bandage can be used within CDP. Bandage pressure can be measured to avoid bandage pressure being too low or too high and to prevent potential damage. Depending on the tolerance and needs of the individual, both low- and high-pressure compression bandages can be applied in the treatment of BCRL. Physiotherapists are hesitant about what pressure to apply the bandage in the treatment of LE. This study has been a guide for physiotherapists to apply the bandage with which pressure depending on the location of the edema.

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Declarations

Ethics approval This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Clinical Research Ethics Committee of Bolu Abant Izzet Baysal University, with decision number 2018/175.

Competing interests The authors declare no competing interests.

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