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[Rafn BS, McNeely ML, Camp PG, Midtgaard J, Campbell KL. Self-measured arm circumference in women with breast cancer is reliable and valid. *Phys Ther.* 2019;99:240–253.]

Published Ahead of Print: October 4, 2018
Accepted: June 21, 2018
Submitted: December 20, 2017

Self-Measured Arm Circumference in Women With Breast Cancer Is Reliable and Valid

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Background. Prospective surveillance by physical therapists enables early detection and treatment of breast cancer–related lymphedema (BCRL). Strategies to increase access to prospective surveillance could reduce the burden of BCRL on patients and the health system. One potential solution is self-managed surveillance that does not require in-person assessment by a specialized physical therapist.

Objective. The objective was to develop and test the reliability and validity of a written and video-supported protocol for women with breast cancer to self-measure arm circumference.

Design. This was a cross-sectional reliability and validity study.

Results. The intrarater reliability between CIR_{self_home} and CIR_{self_lab} and the interrater reliability between CIR_{self_lab} and CIR_{ther} was high to excellent for both arms in both groups (intraclass correlation coefficient $\geq$0.86). VOL_{self_lab} correlated strongly with VOL_{per} ($r \geq 0.95$), demonstrating excellent validity. Participants reported strong intention, self-efficacy, and positive attitude toward the performance of self-managed surveillance for BCRL, which was not perceived to increase worry about having or getting BCRL.

Methods. Participants with (n = 20) and without (n = 21) BCRL completed self-measurement of arm circumference on both arms at home (CIR_{self_home}) and at the lab (CIR_{self_lab}) (intrarater reliability). The CIR_{self_lab} was subsequently compared to measures performed by a specialized physical therapist (CIR_{ther}) (interrater reliability). To test validity, arm volume calculated from the self-measurements (VOL_{self_lab}) was compared to perometry measurements (VOL_{per}). Participants completed a questionnaire to assess attitudes for performing self-managed surveillance for BCRL.

Limitations. These findings need to be replicated in a clinical setting to confirm the reliability and acceptability of self-managed surveillance for BCRL among women newly diagnosed with breast cancer.

Conclusions. Self-measured arm circumference is reliable and valid among women with and without BCRL. Self-managed surveillance for BCRL can support self-efficacy without increasing anxiety.

In 2017, over 247,000 women in the United States were diagnosed with breast cancer and are thus living with or at risk for developing breast cancer–related lymphedema (BCRL).[1] The current model of care for identification of BCRL relies on presentation of significant visible swelling that is identified by the patient or a health care provider. However, this approach often results in missed or delayed diagnoses of BCRL and a protracted wait for the patient to receive necessary treatment,[2,3] which results in complications and more difficult management. Research shows that prospective surveillance for BCRL by a trained physical therapist using sophisticated measurement tools enables early detection and treatment for BCRL and reduces the prevalence of chronic BCRL by 50%.[4–6]

A vital component of prospective surveillance is the ability to perform reliable measures to detect BCRL as early as possible, and once BCRL is established, to monitor arm volume and treat exacerbations early.[7] Traditionally, BCRL is assessed by serial measures of arm circumference by a trained physical therapist using a tape measure. In addition, other objective and reliable measurement tools for monitoring changes in arm volume and fluid content are integrated into clinical practice with the goal of increasing accuracy, speed, and ease of measurement for the physical therapist and patient, and reducing interrater error. These approaches, namely water displacement, perometry, or bioimpedance analysis, are likely more commonly available at specialized clinical sites. However, regardless of measurement approach, the main barriers to a therapist-administered surveillance program are access by patients to the services of a trained physical therapist, the ability of the health care system to deliver the programming (ie, clinical time and resources to follow a patient for several years), and the time and effort of the patient to engage in a program.[8] As a result, prospective surveillance is not part of routine care for many patients with breast cancer.

In contrast to therapist-administered surveillance, a self-managed surveillance approach might be effective at improving uptake of prospective surveillance as part of routine care and ultimately reduce the prevalence of morbidity associated with BCRL. A key question is whether a trained physical therapist is needed to obtain accurate and reliable measures of the arm circumference and volume, or is it possible for women to perform the measurements on their own arms. To date, only 1 study has looked at the correlation of self-measurement with clinically determined measurements of arm circumference and volume in women with breast cancer.[9] Mori et al[9] recruited 17 women with BCRL who had already undergone intensive decongestive treatment, and a physical therapist provided in-person teaching for self-measurement of arm circumference using the traditional tape-measure approach. High correlations were reported between self-measurements and measurements performed by a physical therapist ($r = 0.88$–0.95), and moderate correlations between volumes calculated from circumference measures, obtained by the patient or physical therapist, and water displacement ($r = 0.59$–0.68). These findings indicate that women with BCRL who are familiar with arm circumference measures due to extensive interaction with a physical therapist and receipt of ongoing management of BCRL, and who received in-person teaching by a physical therapist, can self-measure arm circumference in a reliable and valid manner.

To improve the clinical utility of self-managed surveillance for BCRL and reach patients who do not have access to trained physical therapists, we propose that an approach to self-measurement of arm circumference and volume must: (1) be valid and reliable; (2) be easy to understand, learn, and perform; (3) have instructions that do not require in-person teaching; and (4) be inexpensive, accessible, and easy to use and interpret. The purpose of this study was to determine whether women with breast cancer can perform self-measurement of arm circumference in a reliable and valid manner using written and video-supported instructions without in-person teaching by a physical therapist. Specifically, we compared: (1) repeated self-measurements (intrarater reliability) obtained by women with breast cancer; (2) self-measurements with therapist-measurements (interrater reliability), obtained by an experienced physical therapist; and (3) self-measurements with perometer measurements (criterion validity), the gold-standard measure of arm circumference and arm volume. We hypothesized that there would be a high to excellent intrarater and interrater reliability (intraclass correlation coefficient [ICC] ≥ 0.75), and a moderate to high criterion validity ($r \geq 0.5$).

Methods

Design

This study was a cross-sectional reliability and validity study.

Participants

Using posters and postings on University of British Columbia (UBC) websites, we recruited a convenient sample of women who had undergone a surgical procedure for breast cancer with axillary or sentinel lymph node dissection, including those who were undergoing chemotherapy or radiation, aged ≥18 years, who could understand the self-measurement instructions given in English, and who had access and ability to use the internet to view a self-measurement video guide. Participants' ability to understand English was determined during an initial phone call when the study purpose and involvement was explained. Participants with and without a clinical diagnosis of BCRL (defined as ≥200 mL difference between arms measured by perometry[10–13]) were eligible. All participants signed an informed consent form before beginning the study.

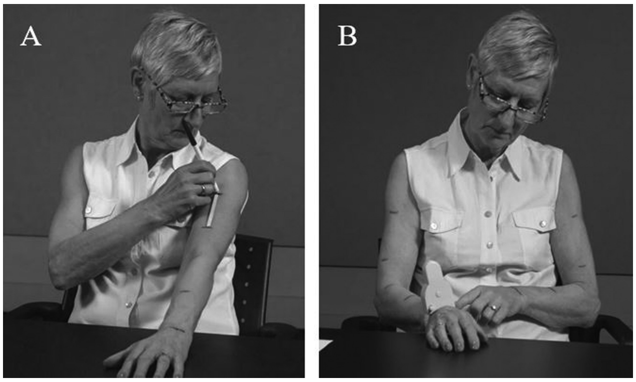


Figure 1.
(A) Marking procedure. (B) Measurement procedure.

Procedures

The procedure included 4 steps: (1) self-measurement at home, (2) self-measurement at the UBC laboratory (lab), (3) measurement by a trained physical therapist at the lab, and (4) perometer measurement at the lab. The lab visit took place within 2 days of the home self-measurement. Participants were asked to wear a sleeveless top for both self-measurements. In addition, for both self-measurements, participants who wore compression garments were asked to remove these 2 hours before the measurement session in order to control for the effect of compression and to allow the stabilization of their BCRL. All circumference measurements were performed with a MyoTape® Body Tape Measure (AccuFitness, Denver, CO, USA), which, traditionally, is used for measuring body composition and tightens with the push of a button to allow for a hand-free measurement.

Arm circumference measurement protocol. A standardized arm circumference measurement protocol was used throughout, with measures performed on both arms at the wrist, and 10, 20, 30, and 40 cm proximal to the wrist. Participants were seated with their arm supported on a table and the shoulder in approximately 30° of forward flexion and 45° of elbow flexion. The wrist landmark and additional measurement points at the set distances from the wrist were marked on the skin with a pen (Fig. 1).

Home self-measurement (CIR_{self_home}). This occurred at participants' homes. Participants received a study package by mail, which contained the consent form, the tape measure, written instructions supplemented with photos illustrating each step of the measurement protocol, and a measurement form to record the self-measures. Further, a website link for the video guide demonstrating how to perform the measurements was emailed to the participants. Participants were asked to first review the written and video material outlining the measurement process before completing a short quiz on the self-measurement technique. Participants then performed the arm circumference measurements of both arms as per the instructions, recorded the measurements on the provided form, and sealed the form in the provided envelope. The envelope with all study material was returned to the study team at the lab for assessment.

Lab self-measurement (CIR_{self_lab}). At the UBC lab visit, participants were asked to repeat the self-measurement of arm circumference with support from the video guide and written instructions, unsupervised by a physical therapist.

Therapist measurement (CIR_{ther}). A single specialized physical therapist with experience in arm circumference measures among women with breast cancer performed arm circumference measures for all participants. The physical therapist was blinded to the participants' self-measurement values.

Perometer measurement. An optoelectronic perometer (Perometer 350S, Pero-system GmbH, Wupertal, Germany) was used to obtain arm circumference and volume measures.[14] Circumference (CIR_{per}) at the same 5 points (the wrist, and 10, 20, 30, and 40 cm proximal to the wrist) and total volume (VOL_{per}) from the wrist to 40 cm proximal to the wrist was obtained for each arm. All participants were assessed twice, and the average of 2 consecutive measurements that were within 1% of each other was recorded.[14–16] If not within 1%, then a third measurement was performed.

Outcome Measures

Measured arm circumference. The CIR_{self_home}, CIR_{self_lab}, and CIR_{ther} were reported in centimeters. Standard error of the CIR_{self_home} measurements (SEM) was calculated from the standard deviations and subsequently used to calculate the minimal detectable change with 95% confidence (95% MDC). Both were reported in centimeters.

Calculated arm volume. The single truncated cone calculation was used to determine arm volume in milliliters (VOL_{self_home}, VOL_{self_lab}, and VOL_{ther}) from arm circumference measures CIR_{self_home}, CIR_{self_lab}, and CIR_{ther}, respectively. The circumference of the arm at the proximal and distal limits of the segment, and the length between those limits, were used to calculate the volume of the segment by using the following formula:

$$\text{Volume} = \frac{h(C_1^2 + C_1 \times C_2 + C_2^2)}{12\pi},$$

where h = height or length of the cone, C_1 = proximal circumference, and C_2 = distal circumference.[17] SEM and 95% MDC were calculated from the volume obtained from the CIR_{self_home} measurements. These were reported in milliliters and percentages, respectively.

Measured arm volume. VOL_{per} was reported in milliliters.

Participant characteristics. Medical and demographic variables were collected in self-report questionnaires at the lab visit. Further, anthropometric measures (height and weight) were collected and used to calculate body mass index (kg/m^2).

Ease of completing self-measurement. The self-reported ease of performing the self-measurements was assessed using a scale from 1 to 10, with higher scores indicating greater ease of performing the measurements.

Motivation to do self-measurement. To assess participants' thoughts about performing self-measures for BCRL, we developed and administered the Thoughts and Beliefs Questionnaire (eAppendix, available at https://academic.oup.com/ptj) following the completion of all measurements at the lab visit. Two versions of the questionnaire were developed, 1 addressed to participants with BCRL and another to participants without BCRL. This 14-item questionnaire was developed using the Theory of Planned Behavior (TPB),[18] the Health Belief Model,[19] and the Self-Regulation Model.[20]

The first section was developed using the Theory of Planned Behavior and included 8 items. Intention to perform self-measures for BCRL was assessed with 2 items (Cronbach alpha = .968). Instrumental attitude was assessed using 2 items (Cronbach α = .913). Planning, subjective norm, self-efficacy, and perceived behavioral control were assessed using 1 item for each scale. These items were all scored on a 7-point Likert scale (1 to 7), with higher scores indicating greater levels of positive thoughts about the self-measures.

The second section of the questionnaire was developed using the Health Belief Model and Self-Regulation Model, and included 5 items. Perceived consequence of BCRL was assessed using 2 items. Perceived risk of BCRL (onset or exacerbation), worry about BCRL, and perceived self-regulation ability were assessed using 1 item for each scale. The 5 items in this section were all scored using a 5-point Likert scale (1 to 5), with higher scores indicating greater levels of negative thoughts about BCRL. The final item, which was not theoretically grounded, asked whether performing self-measures of arm circumference would increase worry about having/getting BCRL, with scores ranking from 1 (not at all) to 5 (very much).

Statistical Analysis

Separate analyses were conducted for participants with and without BCRL. Analyses were performed for the affected and unaffected arm among participants with BCRL, and for the dominant and nondominant arm for participants without BCRL. The intrarater and interrater reliabilities were calculated using the ICC with corresponding 95% CIs for each measurement point (cm) and arm volume (mL). Pearson correlation and the level of agreement between VOL_{self_lab} and VOL_{per} were calculated to determine criterion validity. The mean of these differences (%) were calculated for VOL_{self_lab} and VOL_{per} and illustrated using Bland-Altman plots. The self-reported ease of performing the measurements at home and at the lab was compared using paired t tests.

The motivational data based on the Theory of Planned Behavior were categorized in 3 levels: "strong" for a mean score of $\geq$6, "moderate" for a mean score between 3 and 5, and "weak" for a mean score of $\leq$2. Similarly, the motivational data based on the Health Belief Model and Self-Regulation Model were categorized in 3 levels: "much/very much" for a score of $\geq$4, "neutral" for a score 3, and "not at all/somewhat" for a score of $\leq$2.

Sample Size

Based on our hypothesis of detecting a high to excellent agreement of ICC $\geq$ 0.75 between CIR_{self_home} and CIR_{self_lab} (intrarater reliability) as well as between CIR_{self_lab} and CIR_{ther} (interrater reliability), a sample size of 11 subjects per group was needed (α = .05, 80% power). In order to detect a moderate correlation of $r \geq 0.50$ for criterion validity (VOL_{self_lab} and VOL_{per}), a sample size of 20 subjects per group was needed (α = .05, 80% power).

Role of the Funding Source

The study was funded by the Oncology Division of the Physiotherapy Foundation of Canada. This funding source had no role in the design, execution, analysis, or interpretation of the data.

Results

Forty-one participants were included, specifically 20 participants with and 21 without BCRL, with a mean (standard deviation [SD]) age of 62 (7.5) years and 59 (10.6) years, respectively. Most participants in both groups were highly educated. More participants with BCRL had undergone axillary lymph node dissection and had more lymph nodes removed than participants without BCRL (Tab. 1). All participants completed the study with no missing data across groups.

Among participants without BCRL, there was high to excellent intrarater reliability between CIR_{self_home} and CIR_{self_lab} for all points of measure and volume (ICC $\geq$ 0.86, 95% CI = 0.64–0.94, P < .001) (Tab. 2). Among participants with BCRL, there was excellent intrarater reliability between CIR_{self_home} and CIR_{self_lab} for all points of measure and volume (ICC $\geq$ 0.93, 95% CI = 0.83–0.97, P < .001). Similarly, the interrater reliability was high to excellent between CIR_{self_lab} and CIR_{ther} for all points of measure and volume among participants without BCRL (ICC $\geq$ 0.88, 95% CI = 0.67–0.96, P < .001), and excellent among participants with BCRL (ICC $\geq$ 0.91, 95% CI = 0.41–0.98, P < .001) (Tab. 2). The 95% MDC ranged from 0.35 to 1.56 cm for participants without BCRL and from 0.34 to 1.16 cm among participants with BCRL (Tab. 3). The 95% MDC for the VOL_{self_home} was 110.87 and

Table 1.
Participant Characteristics[a]

Characteristic	Participants With BCRL (n = 20)	Participants Without BCRL (n = 21)	*P*
Age, y, mean (SD)	62.00 (7.46)	58.48 (10.56)	.24
BMI, kg/m^2, mean (SD)	27.97 (4.06)	26.25 (5.62)	.27
Ethnicity			.59
White	17 (85.0)	19 (90.5)	
Asian	3 (15.0)	2 (9.5)	
Marital status			.75
Married/common law	14 (70.0)	13 (61.9)	
Separated/divorced	2 (10.0)	3 (14.3)	
Widowed	2 (10.0)	1 (4.8)	
Single	2 (10.0)	4 (19.0)	
Education			.26
High school	2 (10.0)	0 (0)	
Some university/college	13 (65.0)	13 (61.9)	
Graduate school	5 (25.0)	8 (38.1)	
Family income			.21
<$40,000/y	1 (5.0)	2 (9.5)	
$40,000–$80,000/y	9 (45.0)	7 (33.3)	
$80,000–$100,000/y	10 (50.0)	11 (52.4)	
Not reported	0 (0)	1 (4.8)	
Breast cancer stage			.02
I	0 (0)	6 (28.6)	
II	7 (35.0)	10 (47.6)	
III	12 (60.0)	5 (23.8)	
IV	1 (5.0)	0 (0)	
Surgery			.25
Mastectomy	14 (70.0)	11 (52.4)	
Lumpectomy	6 (30.0)	10 (47.6)	
Postsurgical complications			
Infection	3 (15.0)	3 (14.3)	.95
Drainage issues	5 (25.0)	3 (14.3)	.39
Seroma	3 (15.0)	2 (9.5)	.59
Hematoma	0 (0)	0 (0)	
Lymph node dissection			<.001
Axillary	19 (95.0)	6 (28.6)	
Sentinel	1 (5.0)	14 (66.7)	
Not reported	0 (0)	1 (4.8)	
No. of nodes removed, mean (SD)	13.30 (4.60)	6.55 (7.01)	<.001
Adjuvant treatment			
Chemotherapy	18 (90.0)	18 (85.7)	.68

(continued)

Table 1.
Continued

Characteristic	Participants With BCRL (n = 20)	Participants Without BCRL (n = 21)	*P*
Radiation	17 (85.0)	17 (80.9)	.73
Breast	16 (80.0)	16 (76.2)	.77
Axilla	11 (55.0)	8 (38.1)	.28
Supraclavicular node	5 (25.0)	3 (14.3)	.39
Years since surgery, mean (SD)	7.11 (5.97)	4.09 (4.55)	.17
Years since BCRL onset, mean (SD)	5.09 (5.20)	NA	

[a]Values are reported as number (percentage) of participants unless otherwise indicated. BCRL = breast cancer–related lymphedema; BMI = body mass index; NA = not applicable.

Table 2.
Reliability of Self-Measured Arm Circumference[a]

Point of Measure	Type of Reliability	Participants With BCRL (n = 20)						Participants Without BCRL (n = 21)					
		Affected Arm			Unaffected Arm			Dominant Arm			Nondominant Arm		
		ICC	95% CI	*P*	ICC	95% CI	*P*	ICC	95% CI	*P*	ICC	95% CI	*P*
Wrist	Intrarater	0.96	0.91–0.99	<.001	0.93	0.83–0.97	<.001	0.96	0.89–0.98	<.001	0.95	0.88–0.98	<.001
	Interrater	0.95	0.70–0.99	<.001	0.91	0.42–0.98	<.001	0.91	0.76–0.96	<.001	0.88	0.67–0.96	<.001
10 cm	Intrarater	0.98	0.94–0.99	<.001	0.96	0.89–0.98	<.001	0.91	0.77–0.96	<.001	0.86	0.64–0.94	<.001
	Interrater	0.99	0.97–1.00	<.001	0.97	0.92–0.99	<.001	0.97	0.93–0.99	<.001	0.97	0.93–0.99	<.001
20 cm	Intrarater	0.99	0.96–0.99	<.001	0.98	0.96–0.99	<.001	0.97	0.91–0.99	<.001	0.97	0.93–0.99	<.001
	Interrater	0.99	0.84–1.00	<.001	0.98	0.94–0.99	<.001	0.97	0.91–0.99	<.001	0.98	0.93–0.99	<.001
30 cm	Intrarater	0.93	0.83–0.97	<.001	0.98	0.95–0.99	<.001	0.98	0.95–0.99	<.001	0.96	0.91–0.99	<.001
	Interrater	0.99	0.97–1.00	<.001	0.99	0.96–1.00	<.001	0.99	0.93–1.00	<.001	0.98	0.96–0.99	<.001
40 cm	Intrarater	0.99	0.98–1.00	<.001	0.98	0.95–0.99	<.001	0.99	0.97–1.00	<.001	0.99	0.97–0.99	<.001
	Interrater	1.00	1.00–1.00	<.001	1.00	1.00–1.00	<.001	0.99	0.98–1.00	<.001	1.00	0.99–1.00	<.001
Volume	Intrarater	0.99	0.98–1.00	<.001	0.99	0.98–1.00	<.001	0.98	0.96–0.99	<.001	0.98	0.96–0.99	<.001
	Interrater	1.00	1.00–1.00	<.001	1.00	0.99–1.00	<.001	0.99	0.98–1.00	<.001	0.99	0.97–1.00	<.001

[a]For intrarater reliability, self-measured circumference at home was compared with self-measured circumference at the laboratory and volume calculated from the self-measures performed at home was compared with volume calculated from the self-measures performed at the laboratory. For interrater reliability, self-measured circumference at the laboratory was compared with therapist-measured circumference, and volume calculated from the self-measures performed at the laboratory was compared with therapist-measured volume. BCRL = breast cancer–related lymphedema; ICC = intraclass correlation coefficient.

124.19 mL for the nondominant and dominant arm among participants without BCRL, and 87.59 and 161.19 mL for the unaffected and affected arm among participants with BCRL (Tab. 3). Participants with and without BCRL reported ease of performing the self-measurements both at home and at the lab; with BCRL: CIR_{self_home} 7.4 (SD = 2.2) and CIR_{self_lab} 8.0 (SD = 1.9), $P = .05$, and without BCRL: CIR_{self_home} 6.6 (SD = 2.6) and CIR_{self_lab} 7.3 (SD = 2.2), $P = .04$.

There was an almost perfect correlation between VOL_{self_lab} and VOL_{per} among participants with BCRL ($r = 0.98$, $P < .001$) and those without BCRL ($r = 0.95$, $P < .001$). For participants without BCRL, the difference between VOL_{self_lab} and VOL_{per} was −6.2% (95% CI = −8.7 to −3.6) and −5.9% (95% CI = −9.0 to −2.8) for the dominant and nondominant arm, respectively (Fig. 2A and B). For participants with BCRL, the difference between VOL_{self_lab} and VOL_{per} was −7.7% (95% CI = −9.5 to −5.7) and −4.0% (95% CI = −7.5 to −0.5) for the affected and unaffected arm, respectively (Fig. 2C and D).

Participants reported strong intention to perform the self-measurements at home, positive attitude, and strong self-efficacy toward self-managed surveillance for BCRL (Tab. 4). Further, self-managed surveillance for BCRL was not perceived by most participants to increase worry about developing or having BCRL.

Table 3.
Standard Error of Measurement (SEM) and Minimal Detectable Change (MDC)[a] for Self-Measured Arm Circumference at Home

Point of Measure	Participants With BCRL (n = 20)						Participants Without BCRL (n = 21)					
	Affected Arm			Unaffected Arm			Dominant Arm			Nondominant Arm		
	SD	SEM	MDC	SD	SEM	MDC	SD	SEM	MDC	SD	SEM	MDC
Wrist	1.20	0.20	0.57	0.97	0.26	0.73	0.73	0.15	0.42	0.58	0.12	0.35
10 cm	2.95	0.42	1.16	1.55	0.34	0.93	1.56	0.47	1.30	1.50	0.56	1.56
20 cm	3.22	0.37	1.02	1.73	0.23	0.64	1.60	0.29	0.80	1.44	0.25	0.68
30 cm	3.59	1.03	0.35	2.77	0.35	0.97	2.52	0.35	0.96	2.60	0.50	1.39
40 cm	3.94	0.12	0.34	3.25	0.18	0.49	4.30	0.45	1.25	4.52	0.53	1.48
Volume (mL)	554.15	58.12	161.10	333.09	31.60	87.59	316.82	44.81	124.19	316.21	39.99	110.87
Volume (%)		2.39	6.63		1.65	4.56		2.48	6.87		2.20	6.11

[a]Minimal detectable change with 95% confidence. BCRL = breast cancer–related lymphedema.

Discussion

The developed materials and approach to self-measurement of arm circumference demonstrated excellent reliability among women with and without BCRL. Furthermore, we demonstrated an almost perfect correlation between arm volume calculated from self-measured arm circumference and that obtained from the perometer, indicating high criterion validity. However, in line with previous research,[21] the volume obtained from circumference measurements was 4% to 8% lower than that obtained from the perometer, and the 2 tools should therefore not be used interchangeably in a clinical setting. Lastly, the small measurement errors we demonstrated show the ability of detecting subtle changes in arm circumference using measurements obtained at home by women with breast cancer without in-person teaching by a physical therapist.

We employed a simple protocol of 5 measurement points in accordance with previous research.[22] Although more measurement points will create a more accurate estimation of the total arm volume, we demonstrated perfect correlations between arm volumes calculated from self-measurement and those obtained from the perometer. Further, participants reported that the measurements were easy to perform, with greater ease reported at the second session, possibly because participants were more familiar with the measurement technique. Using this protocol, subtle increases in circumference at the second, third, and fourth measurement points (located at 10, 20, and 30 cm proximal to the wrist) have been demonstrated to predict the onset of subclinical BCRL.[23] The findings by Stout and colleagues[23] suggest that changes at the earliest onset of BCRL would likely occur in the superficial tissue, primarily the forearm and distal upper arm, potentially due to early microlymphatic changes in the deep muscle bulk of the forearm that create a longer route for lymph drainage in this region.[24] Although optimal monitoring for BCRL should be comprehensive with multiple measurement points, Stout et al suggest that the segments 10 to 20 cm and 20 to 30 cm could have the most clinical utility because they account for a large amount of the variance in volume and should be explicitly targeted and monitored for meaningful change.[23] This highlights the importance to include these 3 measurement points (10, 20, and 30 cm proximal to the wrist) when monitoring for BCRL and lends support for the protocol used in the current study.

We demonstrated that self-measurement can detect small changes in arm circumference (95% MDC: 0.3–1.6 cm) and volume (95% MDC: 87.6–161.1 mL, which corresponds to 4.6% and 6.9%) calculated from the self-measurements. Our results align with previous research reporting a similar ability to detect changes in arm circumference (95% MDC: 0.6–1.1 cm)[25] and volume calculated from circumference measurements (90% MDC: 149.7–164.8 mL)[26] or obtained from the perometer (MDC: 3.3% to 29.4%).[27] The measurement error and ability to detect change is calculated from the sample standard deviation and, therefore, determined by the homogeneity of arm size in the study sample. The SEM and MDC in the current study were, therefore, greatest for the affected arm among participants with BCRL, which varied from grade I (10% interlimb difference) to grade III (>30% interlimb difference). As such, for individuals who measure their own arms regularly, the ability to detect change will be better as the variation in any one person's arm size will be much smaller than that seen across a group.

Interlimb differences in 1 circumference of 2 cm[28] or in volume measurement of 5% to 10%[29] might indicate mild (grade I) BCRL. With the demonstrated ability to detect this level of change, self-measurement can, therefore, be used to detect early onset of BCRL. To facilitate early

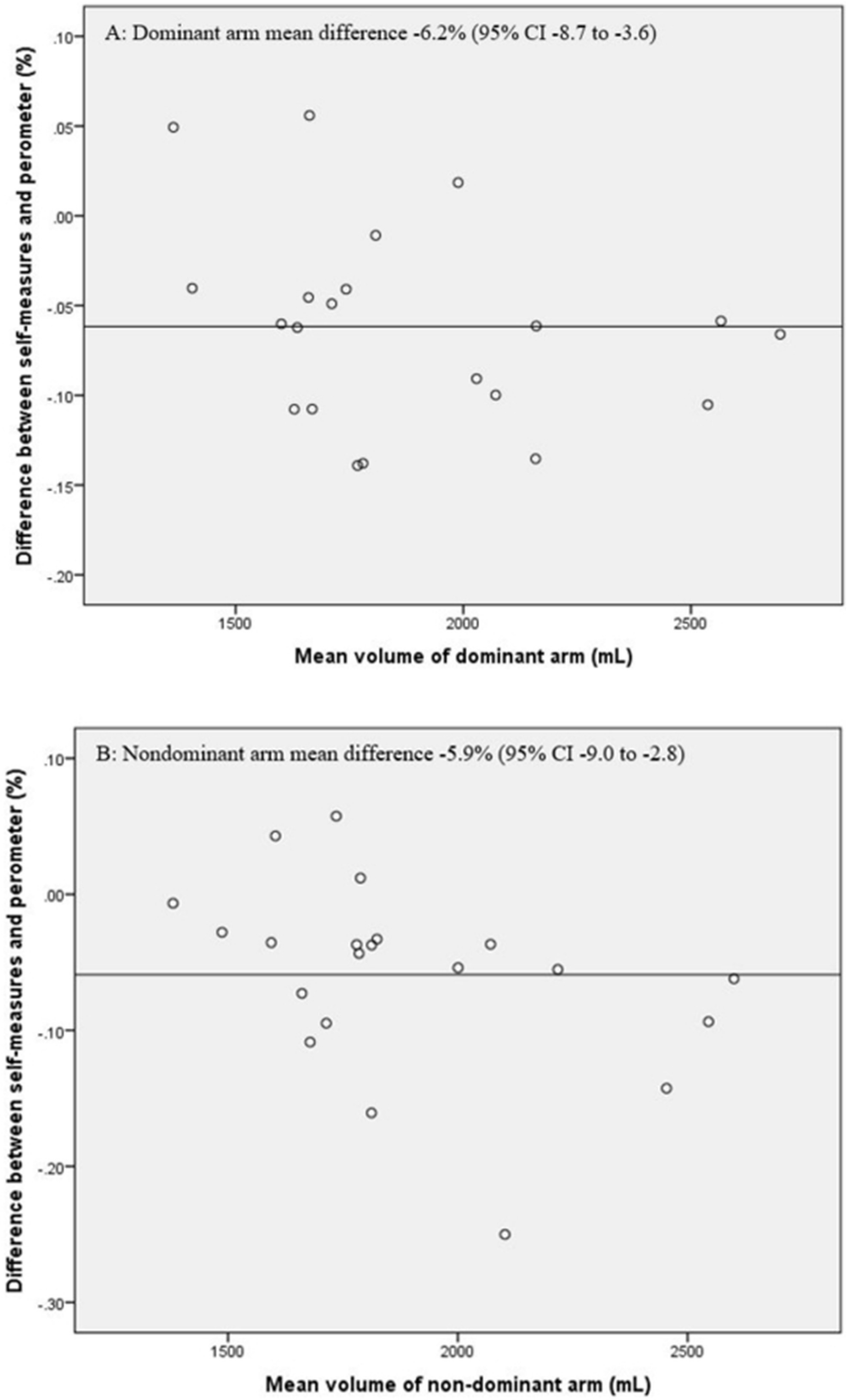
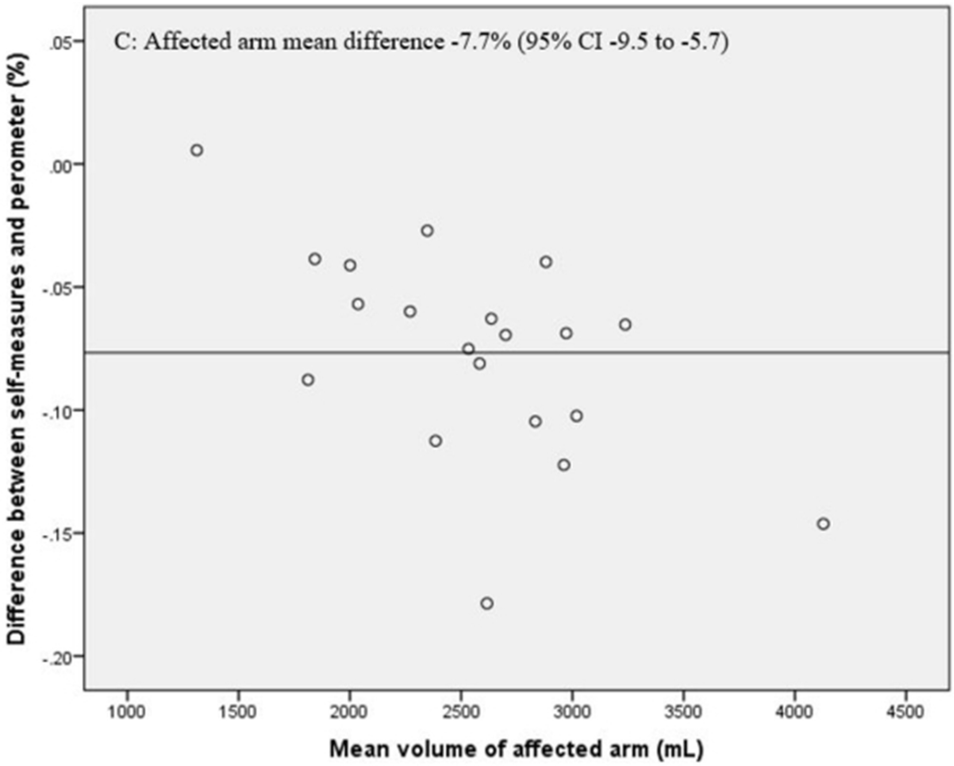


Figure 2.
Agreement between self-measured and perometer-measured arm volume. Bland-Altman plots showing the mean difference and corresponding 95% CIs between arm volumes from perometer (VOL_{per}) and calculated by truncated cone from self-measured arm circumference (VOL_{self_lab}) for: (A) dominant arm among participants without BCRL; (B) nondominant arm among participants without breast cancer–related lymphedema (BCRL); (C) the affected arm among participants with BCRL; and (D) the unaffected arm among participants with BCRL.



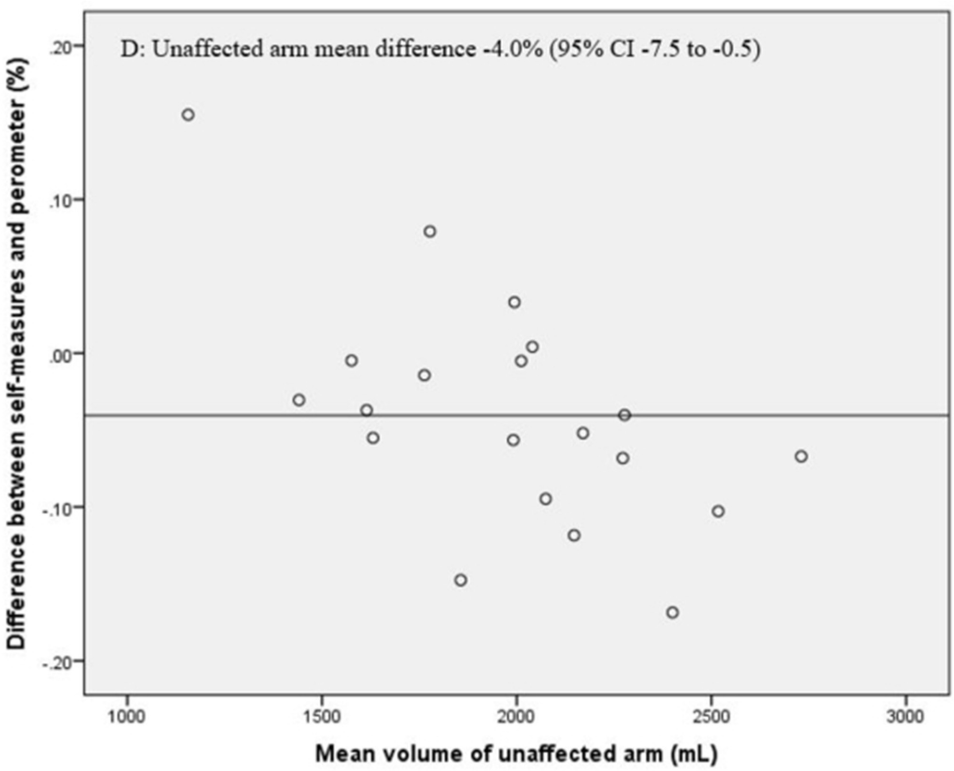


Figure 2.
Continued

Table 4.
Motivation to Perform Self-Measurements for Breast Cancer–Related Lymphedema (BCRL)

Motivational Construct	No. (%) of Participants		*P*
	With BCRL (n = 20)	Without BCRL (n = 21)	
Intention (I intend to do the self-measurements at home every 3 months)			.14
Strong	19 (95.0)	14 (66.7)	
Moderate	1 (5.0)	5 (23.8)	
Weak	0 (0)	2 (9.5)	
Instrumental attitude (I think that self-measurement would be helpful/important)			.28
Positive	18 (90.0)	14 (66.7)	
Neutral	2 (10.0)	6 (28.6)	
Negative	0 (0)	1 (4.8)	
Subjective norm (If I do self-measurement, people who are important to me would be supportive)			.17
Strong	19 (95.0)	17 (81.0)	
Moderate	1 (5.0)	4 (19.0)	
Weak	0 (0)	0 (0)	
Controllability (I have control over whether I do self-measurements every 3 months)			.97
Strong	19 (95.0)	20 (95.2)	
Moderate	1 (5.0)	1 (4.8)	
Weak	0 (0)	0 (0)	
Self-efficacy (I am confident that I can do self-measurements every 3 months)			.17
Strong	19 (95.0)	17 (81.0)	
Moderate	1 (5.0)	4 (19.0)	
Weak	0 (0)	0 (0)	
Planning (I have a plan for how I will do the self-measurements every 3 months)			.02
Strong	18 (90.0)	11 (52.4)	
Moderate	2 (10.0)	5 (23.8)	
Weak	0 (0)	5 (23.8)	
BCRL is a serious condition			.30
Much/very much	19 (95.0)	21 (100)	
Neutral	1 (5.0)	0 (0)	
Not at all/somewhat	0 (0)	0 (0)	
Having/getting BCRL interferes with my life			.01
Much/very much	13 (65.0)	21 (100)	
Neutral	4 (20.0)	0 (0)	
Not at all/somewhat	3 (15.0)	0 (0)	
Perceived risk of BCRL onset/exacerbation			.20
Much/very much	10 (50.0)	6 (28.6)	
Neutral	7 (35.0)	7 (33.3)	
Not at all/somewhat	3 (15.0)	8 (38.1)	

(continued)

Table 4.
Continued

Motivational Construct	No. (%) of Participants		*P*
	With BCRL (n = 20)	Without BCRL (n = 21)	
Self-regulation ability			.58
Much/very much	12 (60.0)	13 (61.9)	
Neutral	6 (30.0)	4 (19.0)	
Not at all/somewhat	2 (10.0)	4 (19.0)	
Worry about getting/having BCRL			.39
Much/very much	13 (65.0)	11 (52.4)	
Neutral	4 (20.0)	3 (14.3)	
Not at all/somewhat	3 (15.0)	7 (33.3)	
Self-measurement would increase my worry about having/getting BCRL			.86
Much/very much	2 (10.0)	3 (14.3)	
Neutral	5 (25.0)	6 (28.6)	
Not at all/somewhat	13 (65.0)	12 (57.1)	

detection, individuals at risk of BCRL should, therefore, seek further evaluation by a health care professional if this degree of increase in self-measured arm circumference is identified (either measured as an interlimb difference or an increase in the at-risk arm over time). Importantly, regardless of measurement technique, it is appropriate to use a combination of objective measurements, physical examination, and patient-reported symptoms (ie, feeling of heaviness) when diagnosing BCRL[30] to minimize the risk of misclassification due to the inherent measurement error associated with all measurement tools.

To further optimize the ability for early detection of BCRL, prediction models (nomograms) have been developed to predict who will develop BCRL based on patient characteristics (age, body mass index), extent of cancer therapy (radiation therapy, axillary surgery, chemotherapy infusions), and postsurgery complications (seroma, swelling).[31,32] However, to date, these models have been demonstrated to be inaccurate in identifying people who develop BCRL in a clinical setting.[32] Frequent monitoring of arm circumference and volume among women at risk for BCRL therefore continues to be the most effective method to enable early detection and intervention to reduce the incidence of clinical BCRL.[33] It has been hypothesized that the time of day for measurement should be consistent for accurate prospective monitoring of arm circumference and volume. However, in this study participants performed the self-measurements at the time of day that was convenient to them and we did not record the time. The time of day for measurements may therefore have varied between the home-based and lab-based self-measurement sessions. Despite this, the demonstrated excellent intrarater reliability indicates that the time of day for measurements might not be important in obtaining accurate measurements, further simplifying the performance of self-managed surveillance for BCRL.

The ability of women with breast cancer to obtain accurate, reliable, and valid measures of arm circumference by self-measurement, without in-person teaching by a physical therapist, is highly relevant due to the growing number of breast cancer diagnoses. New modes of delivering prospective surveillance for BCRL are needed to extend the reach of and promote equal access to surveillance programs to ensure early detection of new onset or exacerbation. Lette[34] developed a device for home measurement of arm volume using the water displacement method and demonstrated high accuracy compared with a traditional, clinic-based water displacement device. However, for people who do not have the skills or energy to build their own water displacement device, using an off-the-shelf tape measure is a simple and efficient alternative option for home circumference measurement.

We demonstrated strong self-efficacy and positive attitudes toward self-measurement among the participants. Independence in the ability to perform objective self-measurement of physiological conditions is suggested to be necessary to promote self-regulation or self-care of BCRL.[35] Further, a positive belief in the controllability of BCRL through early detection and management has been demonstrated to be associated with adherence to risk-management recommendations.[36] In line with this, participants in the current study found the approach easy to learn and perform, and participants with BCRL reported strong intention to use this new approach as a part of their self-care strategies to manage the BCRL. A concern with recommending self-measurement is the potential for increased anxiety related to developing or having BCRL. However, although participants in the study considered BCRL to be a serious condition, most did not associate self-measurement with increased anxiety about developing or having BCRL. These results reflect a 2017 Cochrane review of 22 randomized trials and 4 quasi-randomized trials that demonstrated the benefit of home-based self-management programs in reducing anxiety for women with breast cancer.[37] Future prospective trials are warranted to test if providing the resources and knowledge for self-managed surveillance for BCRL supports self-efficacy, reduces anxiety related to the condition, and supports long-term sustainability of self-surveillance.

Strengths of our study include the development of written instructions and a video guide intended for distance-based delivery of resources to promote self-measurements at home without teaching or supervision by a physical therapist. The goal was to evaluate the reliability and validity of self-measurement as part of an overall self-surveillance strategy for early detection of BCRL. To contain the cost of equipment, an inexpensive tape measure was used that is easily available for online purchase, along with an inexpensive measurement stick. We therefore believe that this approach has high clinical utility to promote independence in detecting changes in arm size, gives easily interpreted outcomes by using low-tech measurement tools, and is supported by educational resources that can be accessed at home. This approach showed excellent reliability for women to obtain consistent measurements across several days; measurements taken by the participant were consistent with those obtained by an experienced physical therapist. Validity was evaluated using the perometer, one of the gold-standard measurement tools.[7] In terms of limitations, 95% of participants had some college or university education, which is a greater proportion than the general population of women in British Columbia, Canada, where 72% have at least some postsecondary education.[38] Although breast cancer incidence is higher among women of higher educational attainment,[39,40] our sampling approach attracted highly educated women who are motivated to participate in research studies, which might have impacted participants' ability to learn and perform the measurements accurately. The study was conducted in a metropolitan area of high socioeconomic status where participants responded to an open call to participate in a laboratory-based study. The findings need to be replicated in a more representative sample. Further, all participants in the study had access to the internet and the performance of the written material alone was not tested. Although our findings support the potential of self-managed surveillance for BCRL, it is imperative that this self-measurement approach is tested in a clinical setting with women who are newly diagnosed for breast cancer to evaluate the reliability and validity within the context of a clinical program. In addition, the effectiveness, cost-effectiveness, and long-term feasibility of self-managed prospective surveillance for BCRL compared with therapist-led prospective surveillance for BCRL must be formally tested.

Clinical Implications

Physical therapists play a key role in advocating for the provision of prospective surveillance and access to physical therapy treatment, to address common side effects of cancer treatment, such as BCRL.[41] For women at risk of BCRL, self-managed surveillance has the potential to provide cost-efficient early detection of onset of BCRL, which can lead to earlier treatment and better prognosis.[2] Women with BCRL are at risk of exacerbations,[42] and this self-measurement approach also offers an opportunity to independently detect exacerbations due to aggravating factors (ie, summer heat, air travel, skin cuts) and monitor the effectiveness of their self-management strategies and compression garments, along with proactively seeking treatment by a physical therapist as needed. This self-measurement approach could thereby provide physical therapists and other clinicians, such as breast surgeons, oncologists, or oncology nurses, with a reliable and valid method for surveillance for BCRL that can reach a greater number of breast cancer survivors, including those living in rural or remote areas, who would otherwise not receive surveillance for BCRL.

Conclusion

Video and written material with instructions on how to perform self-measurement of arm circumference results is reliable and enables valid measurements; it promotes confidence among women with and without BCRL in performing self-measurement. This approach, therefore, has the potential to make a substantial impact on improving the reach of prospective surveillance programs to detect BCRL early and facilitate more timely treatment by a physical therapist.

Author Contributions and Acknowledgment

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The authors wish to acknowledge physical therapist Fatima Inglis for her skilled and invaluable involvement in this study.

Ethics Approval

Ethics approval was provided by the Clinical Research Ethics Board at the University of British Columbia (UBC) (H16-00961). The study was registered at ClinicalTrials.gov (identifier: NCT 0,275,2659).

Funding

The study was funded by the Oncology Division of the Physiotherapy Foundation of Canada.

Clinical Trial Registration

The study was registered at ClinicalTrials.gov (Identifier: NCT 0,275,2659).

Disclosures

The authors completed the ICJME Form for Disclosure of Potential Conflicts of Interest and reported no conflicts of interest.

DOI: 10.1093/ptj/pzy117

References

1 American Cancer Society. Cancer Facts & Figures 2016. https://www.cancer.org/content/dam/cancer-org/research/cancer-facts-and-statistics/annual-cancer-facts-and-figures/2016/cancer-facts-and-figures-2016.pdf. Accessed September 10, 2018.

2 Soran A, Ozmen T, McGuire KP, et al. The importance of detection of subclinical lymphedema for the prevention of breast cancer-related clinical lymphedema after axillary lymph node dissection; a prospective observational study. *Lymphat Res Biol*. 2014;12:289–294.

3 Cheville AL, Beck LA, Petersen TL, Marks RS, Gamble GL. The detection and treatment of cancer-related functional problems in an outpatient setting. *Support Care Cancer*. 2009;17:61–67.

4 Shah C, Arthur DW, Wazer D, Khan A, Ridner S, Vicini F. The impact of early detection and intervention of breast cancer-related lymphedema: a systematic review. *Cancer Med*. 2016;5:1154–1162.

5 Yang EJ, Ahn S, Kim E-K, et al. Use of a prospective surveillance model to prevent breast cancer treatment-related lymphedema: a single-center experience. *Breast Cancer Res Treat*. 2016;160:269–276.

6 Rafn BS, Hung S, Hoens AM, et al. Prospective surveillance and targeted physiotherapy for arm morbidity after breast cancer surgery: a pilot randomized controlled trial. *Clin Rehabil*. 2018;32:811–826.

7 Armer JM, Hulett JM, Bernas M, Ostby P, Stewart BR, Cormier JN. Best practice guidelines in assessment, risk reduction, management, and surveillance for post-breast cancer lymphedema. *Curr Breast Cancer Rep*. 2013;5:134–144.

8 Gerber LH, Stout NL, Schmitz KH, Stricker CT. Integrating a prospective surveillance model for rehabilitation into breast cancer survivorship care. *Cancer*. 2012;118:2201–2206.

9 Mori T, Lustman A, Katz-Leurer M. Self-measurement of upper extremity volume in women post-breast cancer: reliability and validity study. *Physiother Theory Pract*. 2015;31:283–287.

10 Boccardo FM, Ansaldi F, Bellini C, et al. Prospective evaluation of a prevention protocol for lymphedema following surgery for breast cancer. *Lymphology*. 2009;42:1–9.

11 Armer JM, Stewart BR. A comparison of four diagnostic criteria for lymphedema in a post-breast cancer population. *Lymphat Res Biol*. 2005;3:208–217.

12 Box RC, Reul-Hirche HM, Bullock-Saxton JE, Furnival CM. Physiotherapy after breast cancer surgery: results of a randomised controlled study to minimise lymphoedema. *Breast Cancer Res Treat*. 2002;75:51–64.

13 Devoogdt N, Christiaens M-R, Geraerts I, et al. Effect of manual lymph drainage in addition to guidelines and exercise therapy on arm lymphoedema related to breast cancer: randomised controlled trial. *BMJ*. 2011;343:d5326.

14 Stanton AW, Northfield JW, Holroyd B, Mortimer PS, Levick JR. Validation of an optoelectronic limb volumeter (Perometer). *Lymphology*. 1997;30:77–97.

15 Deltombe T, Jamart J, Recloux S, et al. Reliability and limits of agreement of circumferential, water displacement, and optoelectronic volumetry in the measurement of upper limb lymphedema. *Lymphology*. 2007;40:26–34.

16 Czerniec SA, Ward LC, Refshauge KM, et al. Assessment of breast cancer-related arm lymphedema—comparison of physical measurement methods and self-report. *Cancer Invest*. 2010;28:54–62.

17 Lennihan R, Mackereth M. Calculating volume changes in a swollen extremity from surface measurements. *Am J Surg*. 1973;126:649–652.

18 Ajzen I. The theory of planned behavior. In: Van Lange PAM, Kruglanski AW, Higgins ET, eds. *Handbook of Theories of Social Psychology*. Vol. 1. Sage Publishing; 2012: 438–460.

19 Rosenstock I. Historical origins of the health belief model. *Health Educ Monogr*. 1974;2:328–335.

20 Leventhal H, Safer MA, Panagis DM. The impact of communications on the self-regulation of health beliefs, decisions, and behavior. *Health Educ Q*. 1983;10: 3–29.

21 Megens AM, Harris SR, Kim-Sing C, McKenzie DC. Measurement of upper extremity volume in women after axillary dissection for breast cancer. *Arch Phys Med Rehabil*. 2001;82:1639–1644.

22 Foroughi N, Dylke ES, Paterson RD, et al. Inter-rater reliability of arm circumference measurement. *Lymphat Res Biol*. 2011;9:101–107.

23 Stout NL, Pfalzer LA, Levy E, et al. Segmental limb volume change as a predictor of the onset of lymphedema in women with early breast cancer. *PM R*. 2011;3:1098–1105.

24 Mellor RH, Stanton AW, Azarbod P, Sherman MD, Levick JR, Mortimer PS. Enhanced cutaneous lymphatic network in the forearms of women with postmastectomy oedema. *J Vasc Res*. 2000;37:501–512.

25 Devoogdt N, Lemkens H, Geraerts I, et al. A new device to measure upper limb circumferences: validity and reliability. *Int Angiol*. 2010;29:401–407.

26 Taylor R, Jayasinghe UW, Koelmeyer L, Ung O, Boyages J. Reliability and validity of arm volume measurements for assessment of lymphedema. *Phys Ther*. 2006;86: 205–214.

27 Hidding JT, Viehoff PB, Beurskens CHG, Laarhoven HWM van, Sanden MWGN der, Wees PJ van der. Measurement properties of instruments for measuring of lymphedema: systematic review. *Phys Ther*. 2016;96: 1965–1981.

28 BC Cancer Agency. *Symptom management guidelines: lymphedema*. www.bccancer.bc.ca/nursing-site/Documents/9.%20Lymphedema.pdf. Accessed September 10, 2018.

29 National Cancer Institute. *Lymphedema (PDQ®): health professional version*. https://www.cancer.gov/about-cancer/treatment/side-effects/lymphedema/lymphedema-hp-pdq. Accessed September 10, 2018.

30 International Society of Lymphology. The diagnosis and treatment of peripheral lymphedema: 2013 Consensus Document of the International Society of Lymphology. *Lymphology*. 2013;46:1–11.

31 Bevilacqua JLB, Kattan MW, Changhong Y, et al. Nomograms for predicting the risk of arm lymphedema after axillary dissection in breast cancer. *Ann Surg Oncol*. 2012;19:2580–2589.

32 Soran A, Menekse E, Girgis M, DeGore L, Johnson R. Breast cancer-related lymphedema after axillary lymph node dissection: does early postoperative prediction model work? *Support Care Cancer*. 2016;24:1413–1419.

33 Ostby PL, Armer JM, Dale PS, Van Loo MJ, Wilbanks CL, Stewart BR. Surveillance recommendations in reducing risk of and optimally managing breast cancer-related lymphedema. *J Pers Med*. 2014;4:424–447.

34 Lette J. A simple and innovative device to measure arm volume at home for patients with lymphedema after breast cancer. *J Clin Oncol*. 2006;24:5434–5440.

35 Ridner SH, Shih Y-CT, Doersam JK, Rhoten BA, Schultze BS, Dietrich MS. A pilot randomized trial evaluating lymphedema self-measurement with bioelectrical impedance, self-care adherence, and health outcomes. *Lymphat Res Biol*. 2014;12:258–266.

36 Sherman KA, Koelmeyer L. Psychosocial predictors of adherence to lymphedema risk minimization guidelines among women with breast cancer. *Psychooncology*. 2013;22:1120–1126.

37 Cheng KKF, Lim YTE, Koh ZM, Tam WWS. Home-based multidimensional survivorship programmes for breast cancer survivors. *Cochrane Database Syst Rev*. 2017;(8):CD011152.

38 Women and Education. Statistics Canada. https://www.statcan.gc.ca/pub/89-503-x/2010001/article/11542-eng.htm#a3. Accessed September 10, 2018.

39 van Loon AJ, Brug J, Goldbohm RA, van den Brandt PA, Burg J. Differences in cancer incidence and mortality among socio-economic groups. *Scand J Soc Med*. 1995;23: 110–120.

40 Robert SA, Strombom I, Trentham-Dietz A, et al. Socioeconomic risk factors for breast cancer: distinguishing individual- and community-level effects. *Epidemiology*. 2004;15:442–450.

41 Stout NL, Binkley JM, Schmitz KH, et al. A prospective surveillance model for rehabilitation for women with breast cancer. *Cancer*. 2012;118:2191–2200.

42 Bar Ad V, Cheville A, Solin LJ, Dutta P, Both S, Harris EER. Time course of mild arm lymphedema after breast conservation treatment for early-stage breast cancer. *Int J Radiat Oncol Biol Phys*. 2010;76:85–90.