Upper Extremity Strength Imbalance after Mastectomy and the Effect of Resistance Training

Authors
Melissa J. Benton[1], Maura C. Schlairet[2]

Affiliations
1 University of Colorado Colorado Springs, Helen & Arthur E. Johnson Beth-El College of Nursing & Health Sciences, Colorado Springs, United States
2 Mercer University, Georgia Baptist College of Nursing, Atlanta, United States

Key words
breast cancer, exercise training, arm curl

received 14.04.2017
revised 15.06.2017
accepted 18.06.2017

Bibliography
DOI https://doi.org/10.1055/s-0043-115105
Sports Medicine International Open 2017; 1: E160–E165

ISSN 2367-1890

Correspondence
Dr. Melissa J. Benton
University of Colorado Colorado Springs
Helen & Arthur E. Johnson Beth-El College of Nursing & Health Sciences
1420 Austin Bluffs Parkway
Colorado Springs, 80918
United States
Tel.: +1/719/255 4140, Fax: +1/719/255 4496
mbenton@uccs.edu

ABSTRACT

The purpose of this non-randomized pre/post comparison trial was to explore the effect of resistance training (RT) on upper extremity strength imbalance in breast cancer survivors. Seventeen right-side dominant female breast cancer survivors (age: 58.2 ± 2.7 years; BMI: 27.8 ± 1.1 kg/m^2) with right-sided (RSM) or left-sided (LSM) mastectomy completed strength testing (30-second arm curl) before and after an 8-week RT program. At baseline, LSM (n = 8) had equal strength bilaterally (right = 16.8 ± 1.1 repetitions; left = 16.4 ± 1.4 repetitions), whereas RSM (n = 9) had impaired strength on the right (16.7 ± 1.3 repetitions) compared to the left (18.6 ± 1.1 repetitions) side ($p < 0.01$). After RT, RSM increased strength by 25 % on the right (initially weaker) side and 19 % on the left (initially stronger) side, which resolved the imbalance. By comparison LSM increased 19 % on both sides that were initially equal in strength. Based on our findings, breast cancer survivors with dominant-side mastectomy are at risk for upper extremity strength imbalance that can be resolved with a relatively short-term RT program.

Introduction

Among breast cancer survivors, surgical mastectomy results in damage to the axillary area, including muscle, nerve and circulatory tissues [10]. Over time, this damage can cause muscular atrophy with loss of upper body strength and function [10, 38]. Mastectomy rates are increasing and are estimated to be 45 % among women of all ages who have been diagnosed with breast cancer [11]. The increasing incidence of surgical mastectomy places breast cancer survivors at risk for development of upper extremity strength imbalances [17, 28, 39, 42].

Side-to-side muscle imbalance has been well studied among athletes [4, 9, 12, 22, 23, 26, 27, 34, 43]. Findings indicate that strength imbalances increase the risk for acute [12, 34, 43] and chronic injury [4, 23, 26], and that rehabilitation with resistance training can resolve these imbalances and decrease risk for injury [9, 33]. Less is known about non-athletic populations, although among healthy younger adults [20] and older clinical populations [25, 40] evidence regarding risk is consistent with that of athletes.

In healthy women, upper extremity strength should be relatively equal bilaterally [21, 32]. However, compared to healthy women, breast cancer survivors have greater upper extremity loss of strength, leading to functional impairment [15]. Traditionally, after mastectomy women have been instructed to avoid all lifting and muscular exertion with their treated arm [36], so surgically-induced atrophy leading to muscular imbalance may have gone relatively unappreciated. However, women must have full functional use of both upper extremities for participation in normal activities of daily living. In particular, tasks requiring elbow flexion, including lifting and carrying, are difficult for women who have undergone mastectomy after breast cancer [18].

Research evaluating upper extremity strength imbalance in breast cancer survivors has been inconsistent. Three observational studies reported greater strength loss on the affected side using either a multi-joint chest or shoulder press [28] or a single-joint shoulder raise [39, 42], whereas one reported greater loss on the non-affected side using a combined upright row/shoulder press exercise [17]. One intervention study reported baseline strength differences, with greater weakness on the affected side, using electromyographic (EMG) analysis of the pectoralis major and triceps brachii.[14] None of these studies evaluated elbow flexion, although it is the most problematic movement for this population. Furthermore, although intervention studies demonstrate overall increases in upper extremity strength in breast cancer survivors after a resistance training program, strength has primarily been measured using a chest press involving elbow extension [8, 37, 44, 45]. Only one study evaluated strength using an arm curl to measure elbow flexion [29]. Unfortunately, none of these studies measured side-to-side differences in upper extremity strength. Finally, in the only intervention study to evaluate side-to-side differences, EMG was used for measurement, and although strength increased in both upper extremities, differences were not resolved with training [14]

Intervention studies evaluating imbalances in elbow flexion strength in breast cancer survivors after mastectomy are needed. The 30-second arm curl (flexion) test is a well-recognized field measure of upper extremity strength and functional ability. It has been validated as a surrogate for direct laboratory measurement of maximal upper-body strength [2, 35]. The 30-second arm curl test is an appropriate measurement tool for evaluation of impairments in upper extremity strength related to elbow flexion. This study was designed to explore the effect of resistance training on upper extremity strength imbalance in breast cancer survivors after unilateral mastectomy using the arm curl test to measure elbow flexion strength. Our hypothesis was that the affected side would be initially weaker and that this imbalance would be resolved with resistance training.

Methods

Seventeen female breast cancer survivors (time since diagnosis = 6.3 ± 1.8 years) with unilateral mastectomy were included in the pilot study after receiving informed consent. All were recruited from the community by flyers and word of mouth as part of a larger resistance training study for breast cancer survivors at least 30 years of age that has previously been described [3]. Nine had right-sided mastectomy (RSM) and eight had left-sided mastectomy (LSM). All were right-arm dominant. Exclusion criteria were bilateral mastectomy, lymphedema, pregnancy or the intent to become pregnant, participation in any regular exercise program, or any medical condition limiting participation in an exercise program. All participants completed anthropometric and upper extremity strength measurement before and after an 8-week resistance training program. All testing and training was done in a university research center by the same experienced investigator. The study was approved by the university institutional review board for protection of human subjects and conducted in accordance with the ethical standards of this journal [16].

Anthropometrics

Height was measured in centimeters using a wall-mounted stadiometer with the measuring tongue aligned with the top of the participant's head. Participants removed their shoes and positioned themselves with their backs aligned against the wall and heads erect.

Weight was measured in kilograms using a portable computerized scale. Participants removed their shoes and voided prior to the procedure.

Waist circumference was measured in centimeters at the level of the umbilicus using standardized procedures following the guidelines of Callaway et al.[5] A Gulick tape was used to ensure constant tension during measurement.

Upper extremity strength measurement

For the arm curl test, participants sat upright in a straight-backed chair with both feet flat on the floor and a 5 lb dumbbell held laterally in their untreated (non-mastectomy) hand. The investigator stabilized their elbow at their side while they repeatedly raised and lowered the dumbbell through a full range of motion. The test was then repeated on the treated (mastectomy) side. Partial curls that did not complete the full range of motion were not counted. The number of full curls completed in 30 s with good form was recorded as the score for each arm.

Resistance training

The 8-week resistance training program has previously been described [3]. Briefly, participants completed two sessions per week for 8 weeks with at least 2 days rest between sessions. Adherence was 97 %. All sessions were directly supervised by the same investigator. A total-body progressive training strategy was used. Participants completed three sets each of a seated chest press, shoulder press, parallel grip cable pulldown, standing cable bar curls, and standing cable bar pushdowns for the upper body, and a seated leg press, leg extensions, and lying leg curls for the lower body using pin-loaded weight machines (Precor, USA). Participants were asked to achieve 8–12 repetitions at a given weight, and when they were able to complete 10–12 repetitions with good form for all 3 sets, the weight was increased 5–10 % at the next training session. To minimize training time, exercises were paired into opposing supersets, with the exception of the leg press, which was trained alone with a one-minute rest between sets.

Statistical analysis

Data were analyzed using SPSS version 22, with a level of significance set at $p < 0.05$. All data were reported as mean and standard error (SE). Participant characteristics were analyzed using descriptive statistics, and differences between and within groups were evaluated using repeated measures analysis of variance (ANOVA) and independent samples t-tests. As a surrogate for clinical significance, effect sizes were calculated as eta-squared (η^2). An effect size of 0.01 was considered small, 0.06 was considered medium, and 0.14 was considered large [13].

Results

As a single group, participants were middle-aged (age: 58.2 ± 2.7 years), overweight (BMI: 27.8 ± 1.1 kg/m^2), and centrally obese (waist circumference: 89.7 ± 2.6 cm). There were no significant differences between participants with RSM and LSM for age or anthropometric measurements (▶ **Table 1**). At baseline, the LSM group that was status post-mastectomy on the non-dominant side was observed to have equal upper extremity strength bilaterally (▶ **Fig. 1**). There was no significant difference in arm curl repetitions achieved in 30 s between the dominant right and non-dominant left sides (16.8 ± 1.2 repetitions and 16.4 ± 1.4 repetitions, respectively). By comparison, the RSM group demonstrated significantly greater (11 %) weakness on the dominant right side compared to the non-dominant left side (16.7 ± 1.3 repetitions versus 18.6 ± 1.1 repetitions, $p < 0.01$; $\eta^2 = 0.07$).

After participation in 8 weeks of resistance training two times a week, all participants were significantly stronger ($p < 0.001$) and the RSM group no longer demonstrated right-sided weakness (▶ **Fig. 2**). Specifically, the RSM group increased arm curl repetitions by 25 % ($p < 0.001$; $\eta^2 = 0.35$) on the dominant (initially weaker) side and 19 % ($p < 0.001$; $\eta^2 = 0.27$) on the non-dominant (initially stronger) side; and the LSM group increased 19 % ($p < 0.01$; $\eta^2 = 0.32$) on the dominant and 19 % ($p < 0.01$; $\eta^2 = 0.28$) on the non-dominant sides that were initially equal in strength. Furthermore, although training volume load increased significantly over the 8-week period, there were no between-group differences in any of the five upper body exercises used either before or after the training program (▶ **Table 2**).

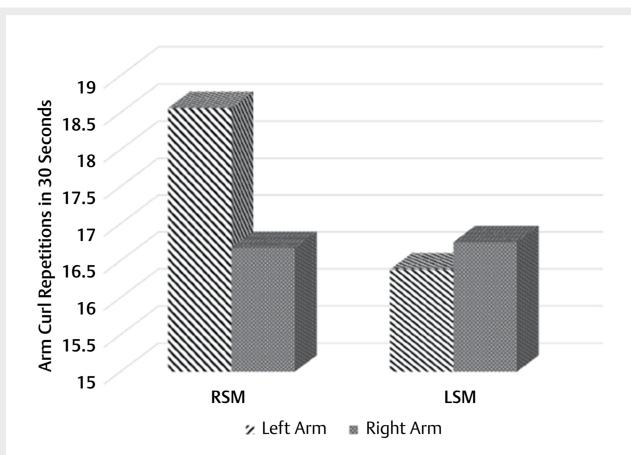
Discussion

The principal finding of this study was that women who experience surgical mastectomy on their dominant right side demonstrate a significant imbalance in upper extremity strength, and that a program of progressive resistance training only two days a week over an 8-week period can reverse that imbalance. Although it is well-recognized that resistance training can improve upper extremity strength in breast cancer survivors [6, 37], its effect on strength imbalance secondary to surgical mastectomy is unclear. Among

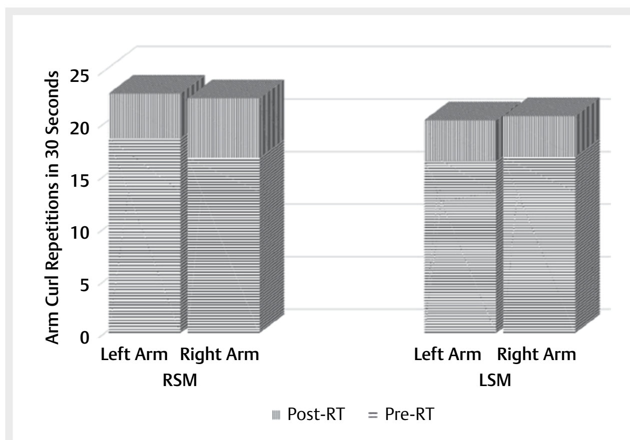
▶ **Table 1** Anthropometric and upper extremity strength measurements before and after resistance training in 17 right-arm-dominant women with unilateral mastectomy.

	RSM (n = 9)		**LSM (n = 8)**	
	Baseline	**After RT**	**Baseline**	**After RT**
Age (years)	60.6 ± 3.4		55.5 ± 4.3	
Weight (kg)	76.2 ± 4.2	76.7 ± 4.1	69.4 ± 5.0	68.7 ± 4.9
Body Mass Index (kg/m²)	27.2 ± 1.5	27.4 ± 1.5	28.4 ± 1.8	28.2 ± 1.6
Waist Circumference (cm)	91.0 ± 3.6	89.8 ± 3.2	88.2 ± 3.9	87.9 ± 4.4
Arm Curls (repetitions)				
Right	16.7 ± 1.3 *	22.3 ± 1.5 ††	16.8 ± 1.2	20.6 ± 0.9 ‡‡
Left	18.6 ± 1.1 *	22.8 ± 1.3 †	16.4 ± 1.4	20.3 ± 1.0 ‡

Data presented as Mean ± SE. * Significant difference between right and left sides ($p < 0.01$; $\eta^2 = 0.07$); † Significant improvement from baseline ($p < 0.001$; $\eta^2 = 0.27$); †† Significant improvement from baseline ($p < 0.001$; $\eta^2 = 0.35$); ‡ Significant improvement from baseline ($p < 0.01$; $\eta^2 = 0.28$); ‡‡ Significant improvement from baseline ($p < 0.01$; $\eta^2 = 0.32$); **RSM** = right side mastectomy; **LSM** = left side mastectomy; **RT** = resistance training



▶ **Fig. 1** Comparison of side-to-side upper extremity differences before 8 weeks of resistance training**.** In women with mastectomy on the dominant side (RSM), the dominant arm was 11 % weaker than the non-dominant arm ($p < 0.01$; $\eta^2 = 0.07$), whereas women with mastectomy on the non-dominant arm (LSM) had equal strength bilaterally.



▶ **Fig. 2** Comparison of side-to-side upper extremity differences after 8 weeks of resistance training. In women with mastectomy on the dominant side (RSM), there was a 25 % increase ($p < 0.001$; $\eta^2 = 0.35$) in strength in the dominant (right) arm and a 19 % increase ($p < 0.001$; $\eta^2 = 0.27$) in the non-dominant (left) arm that completely compensated for the initial imbalance. In women with mastectomy on the non-dominant side (LSM), there was a 19 % increase bilaterally ($p < 0.01$; $\eta^2 = 0.28–0.32$) that resulted in no side-to-side difference either before or after training.

▶ **Table 2** Changes in training volume load (total repetitions X load) for upper body exercises over the 8-week resistance training program. Both groups increased significantly and there were no differences between groups either before or after training.

	RSM (n = 9)		**LSM (n = 8)**	
	Baseline	**After RT**	**Baseline**	**After RT**
Seated Chest Press (kg)	411 ± 44	698 ± 55 †	419 ± 42	721 ± 47 †
Parallel Grip Cable Pulldown (kg)	515 ± 37	716 ± 62 †	438 ± 57	672 ± 51 †
Shoulder Press (kg)	259 ± 27	589 ± 46 †	258 ± 24	607 ± 24 †
Standing Cable Bar Curls (kg)	221 ± 24	330 ± 40 †	200 ± 14	327 ± 25 †
Standing Cable Bar Pushdowns (kg)	245 ± 26	367 ± 36 †	218 ± 12	381 ± 26 †

Data presented as Mean ± SE. **RSM** = right side mastectomy; **LSM** = left side mastectomy; **RT** = resistance training; **†** Significant improvement from baseline ($p < 0.001$; $\eta^2 = 0.72–0.94$)

participants who demonstrated baseline imbalance, strength gains in the initially weaker upper extremity were approximately 50 % greater than in the initially stronger upper extremity, although a bilateral training strategy was used. Specifically, rather than being asked to train each arm individually, a more time-efficient approach was employed in which participants used two-handed grip machines and bars that distributed exertion equally between both upper extremities. As a result, after only 16 training sessions, gains were such that bilateral strength was equalized and there was complete compensation for the initial imbalance.

The effect of resistance training on side-to-side strength differences has not been widely studied. In a previous study, Janzen and colleagues [21] evaluated the effect of 26 weeks of bilateral upper extremity training (chest press, shoulder press, latissimus pulldown, biceps curl) three days a week on unilateral upper extremity strength in healthy post-menopausal women, using the latissimus pulldown for strength measurement. There were no appreciable side-to-side differences prior to training, and after the training program unilateral upper extremity strength improved equally between sides [21]. Although they measured strength using a different exercise than the present study, their training protocol was similar and included the same upper body exercises that the breast cancer survivors in our study completed. It would seem probable, therefore, that had they measured changes in the biceps (arm) curl, side-to-side strength increases would also have been relatively equal. By comparison, we also observed bilaterally equal strength increases in participants who initially had no side-to-side strength differences; but among those who exhibited an initial imbalance in upper extremity strength, we observed not only overall, but differential increases that resolved side-to-side differences. Hence, it would appear that when unilateral strength is similar, a bilateral stimulus increases both sides equally, but when imbalance is present there is a differential effect favoring the weaker side.

In a more recent study, Hagstrom and colleagues [14] evaluated the effect of a 16-week whole-body resistance training program on side-to-side differences in pectoralis and triceps strength in breast cancer survivors. At baseline, the affected side was found to be weaker, which agrees with our baseline findings; but contrary to our results, the training program they reported did not resolve the initial imbalance. The difference in outcomes may have been related to their training protocol. The upper body exercises they utilized were compound, multi-joint exercises (chest press, back row, lat pulldown), which may have allowed selective recruitment of stronger muscle groups that compensated for weaker ones. By comparison, our training program utilized both multi- and single-joint exercises that allowed isolation of specific muscle groups, in particular the biceps brachii used for elbow flexion. It is possible that if Hagstrom and colleagues[14] had used isolation exercises such as chest flyes or triceps extensions, the side-to-side imbalance they observed may have been resolved.

Consideration should be given to bilateral versus unilateral training. Unilateral training involves training one side only for the purpose of increasing strength on both sides [30]. It is used in clinical populations exhibiting weakness or immobility on one side, such as stroke patients [41]. Although the cross-education effect of unilateral upper extremity training is well recognized [24], gains in the trained extremity have consistently been found to exceed gains in the untrained extremity [1, 19, 31, 32]. Therefore, in this population unilateral training of the stronger side only would be unlikely to resolve the imbalance by sufficiently strengthening the weaker side.

Unilateral training can also involve training both sides separately. In the same study of post-menopausal women previously discussed, Janzen and colleagues [21] evaluated unilateral training of both upper extremities. Their results mirrored those of bilateral training. Upper extremity strength, which was equal bilaterally at baseline, increased equally on each side with either bilateral (both upper extremities trained together) or unilateral (both upper extremities trained separately) training. Although it is possible that unilateral training of both upper extremities would resolve side-to-side strength differences to the same extent as bilateral training, bilateral training is more time-efficient [21] and, because participants can achieve more repetitions with less perceived exertion [7], may be better tolerated.

We recognize that there are limitations to our study that include a small sample size. However, all of the effect sizes were medium and large, which supports the clinical significance of our data. Furthermore, all of the participants were right-hand dominant. Although with a small sample size, it was considered important to control for arm dominance by including only right-hand dominant participants, it may have affected the outcomes. Our use of the 30-second arm curl test to measure strength may also be considered a limitation. Although the arm curl test has been validated against a maximal (1RM) chest press [2, 35], the 30-second timespan involves muscular endurance as well as strength. However, we considered measurement of maximal (1RM) elbow flexion as potentially dangerous in this population, so made an a priori decision that may have influenced our findings. Finally, potential differences in muscle mass between the treated and untreated sides were not assessed. Both muscle quality (strength) and quantity (mass) should be considered in light of the potential effects of surgery on upper extremity musculature. Future intervention studies should include a larger sample size with both right- and left-arm-dominant women, and evaluate muscle mass as an outcome.

Conclusions

Our results demonstrate a statistically and clinically significant imbalance in upper extremity strength among women with mastectomy on their dominant side, which may place them at risk for either acute or chronic injury. Although our findings are preliminary, they demonstrate the feasibility of an 8-week resistance training program to resolve this strength imbalance. More research is needed to identify the most appropriate testing and training strategies for this population.

Acknowledgements

Acknowledgements: This study was supported by a J. Patrick Barnes grant from the Daisy Foundation.

Conflict of Interest

The authors have no conflicts of interest to disclose.

References

[1] Bemben MG, Murphy RE. Age related neural adaptation following short term resistance training in women. J Sports Med Phys Fitness 2001; 41: 291–299

[2] Benton MJ, Alexander JL. Validation of functional fitness tests as surrogates for strength measurement in frail, older adults with chronic obstructive pulmonary disease. Am J Phys Med Rehabil 2009; 88: 579–583

[3] Benton MJ, Schlairet MC, Gibson DR. Change in quality of life among breast cancer survivors after resistance training: Is there an effect of age? J Aging Phys Act 2014; 22: 178–185

[4] Burnham RS, May L, Nelson E, Steadward R, Reid DC. Shoulder pain in wheelchair athletes. The role of muscle imbalance. Am J Sports Med 1993; 21: 238–242

[5] Callaway CW, Chumlea WC, Bouchard C, Himes JH, Lohman TG, Martin AD, Mitchell CD. Circumferences. In: Lohman TG.ed. Anthropometric Standardization Reference Manual. Champaign, IL: Human Kinetics; 1988: 44–46

[6] Cheema BS, Kilbreath SL, Fahey PP, Delaney GP, Atlantis E. Safety and efficacy of progressive resistance training in breast cancer: A systematic review and meta-analysis. Breast Cancer Res Treat 2014; 148: 249–268

[7] Costa E, Moreira A, Cavalcanti B, Krinski K, Aoki M. Effect of unilateral and bilateral resistance exercise on maximal voluntary strength, total volume of load lifted, and perceptual and metabolic responses. Biol Sport 2015; 32: 35–40

[8] Courneya KS, Segal RJ, Mackey JR, Gelmon K, Reid RD, Friedenreich CM, Ladha AB, Proulx C, Vallance JK, Lane K, Yasui Y, McKenzie DC. Effects of aerobic and resistance exercise in breast cancer patients receiving adjuvant chemotherapy: A multicenter randomized controlled trial. J Clin Oncol 2007; 25: 4396–4404

[9] Croisier JL, Forthomme B, Namurois MH, Vanderthommen M, Crielaard JM. Hamstring muscle strain recurrence and strength performance disorders. Am J Sports Med 2002; 30: 199–203

[10] Dasgupta S, Sanyal S, Sengupta SP. Transpectoral anterior approach to the axilla for lymph node dissection in association with mastectomy preserving both pectoral muscles and their neurovascular bundles. Tumori 1999; 85: 498–502

[11] Dragun AE, Huang B, Tucker TC, Spanos WJ. Increasing mastectomy rates among all age groups for early stage breast cancer: A 10-year study of surgical choice. Breast J 2012; 18: 318–325

[12] Edouard P, Degache F, Oullion R, Plessis JY, Gleizes-Cervera S, Calmels P. Shoulder strength imbalances as injury risk in handball. Int J Sports Med 2013; 34: 654–660

[13] Fritz CO, Morris PE, Richler JJ. Effect size estimates: Current use, calculations, and interpretation. J Exp Psychol Gen 2012; 141: 2–18

[14] Hagstrom AD, Shorter KA, Marshall PW. Changes in unilateral upper limb muscular strength and EMG activity following a 16 week strength training intervention survivors of breast cancer. J Strength Cond Res 2017, doi:10.1519/JSC.0000000000001890

[15] Harrington S, Padua D, Battaglini C, Michener LA, Giuliani C, Myers J, Groff D. Comparison of shoulder flexibility, strength, and function between breast cancer survivors and healthy participants. J Cancer Surviv 2011; 5: 167–174

[16] Harriss DJ, Atkinson G. Ethical standards in sport and exercise science research: 2016 update. Int J Sports Med 2015; 36: 1121–1124

[17] Hayes S, Battistutta D, Newman B. Objective and subjective upper body function six months following diagnosis of breast cancer. Breast Cancer Res Treat 2005; 94: 1–10

[18] Hayes SC, Battistutta D, Parker AW, Hirst C, Newman B. Assessing task "burden" of daily activities requiring upper body function among women following breast cancer treatment. Support Care Cancer 2005; 13: 255–265

[19] Hubal MJ, Gordish-Dressman H, Thompson PD, Price TB, Hoffman EP, Angelopoulos TJ, Gordon PM, Moyna NM, Pescatello LS, Visich PS, Zoeller RF, Seip RL, Clarkson PM. Variability in muscle size and strength gain after unilateral resistance training. Med Sci Sports Exerc 2005; 37: 964–972

[20] Jacobs C, Uhl TL, Seeley M, Sterling W, Goodrich L. Strength and fatigability of the dominant and nondominant hip abductors. J Athl Train 2005; 40: 203–206

[21] Janzen CL, Chilibeck PD, Davison KS. The effect of unilateral and bilateral strength training on the bilateral deficit and lean tissue mass in post-menopausal women. Eur J Appl Physiol 2006; 97: 253–260

[22] Jung H, Lee N, Park S. Interaction of ACTN3 gene polymorphism and muscle imbalance effects on kinematic efficiency in combat sports athletes. J Exerc Nutrition Biochem 2016; 20: 1–7

[23] Knapik JJ, Bauman CL, Jones BH, Harris JM, Vaughan L. Preseason strength and flexibility imbalances associated with athletic injuries in female collegiate athletes. Am J Sports Med 1991; 19: 76–81

[24] Lee M, Carroll TJ. Cross education: Possible mechanisms for the contralateral effects of unilateral resistance training. Sports Med 2007; 37: 1–14

[25] Lin JJ, Wu YT, Wang SF, Chen SY. Trapezius muscle imbalance in individuals suffering from frozen shoulder syndrome. Clin Rheumatol 2005; 24: 569–575

[26] Lucado AM, Kolber MJ, Cheng MS, Echternach JL Sr. Upper extremity strength characteristics in female recreational tennis players with and without lateral epicondylalgia. J Orthop Sports Phys Ther 2012; 42: 1025–1031

[27] Luk HY, Winter C, O'Neill E, Thompson BA. Comparison of muscle strength imbalance in powerlifters and jumpers. J Strength Cond Res 2014; 28: 23–27

[28] Merchant CR, Chapman T, Kilbreath SL, Refshauge KM, Krupa K. Decreased muscle strength following management of breast cancer. Disabil Rehabil 2008; 30: 1098–1105

[29] Milne HM, Wallman KE, Gordon S, Courneya KS. Effects of a combined aerobic and resistance exercise program in breast cancer survivors: A randomized controlled trial. Breast Cancer Res Treat 2008; 108: 279–288

[30] Munn J, Herbert RD, Gandevia SC. Contralateral effects of unilateral resistance training: A meta-analysis. J Appl Physiol 2004; 96: 1861–1866

[31] Munn J, Herbert RD, Hancock MJ, Gandevia SC. Training with unilateral resistance exercise increases contralateral strength. J Appl Physiol 2005; 99: 1880–1884

[32] Nickols-Richardson SM, Miller LE, Wootten DF, Ramp WK, Herbert WG. Concentric and eccentric isokinetic resistance training similarly increases muscular strength, fat-free soft tissue mass, and specific bone mineral measurements in young women. Osteoporos Int 2007; 18: 789–796

[33] Niederbracht Y, Shim AL, Sloniger MA, Paternostro-Bayles M, Short TH. Effects of a shoulder injury prevention strength training program on eccentric external rotator muscle strength and glenohumeral joint imbalance in female overhead activity athletes. J Strength Cond Res 2008; 22: 140–145

[34] Noffal GJ. Isokinetic eccentric-to-concentric strength ratios of the shoulder rotator muscles in throwers and nonthrowers. Am J Sports Med 2003; 31: 537–541

[35] Rikli RE, Jones CJ. Development and validation of a functional fitness test for community-residing older adults. J Aging Phys Act 1999; 7: 127–159

[36] Schmitz KH. Balancing lymphedema risk: Exercise versus deconditioning for breast cancer survivors. Exerc Sport Sci Rev 2010; 38: 17–24

[37] Schmitz KH, Ahmed RL, Troxel A, Cheville A, Smith R, Lewis-Grant L, Bryan CJ, Williams-Smith CT, Greene QP. Weight lifting in women with breast-cancer-related lymphedema. N Engl J Med 2009; 361: 664–673

[38] Sclafani LM, Baron RH. Sentinel lymph node biopsy and axillary dissection: added morbidity of the arm, shoulder and chest wall after mastectomy and reconstruction. Cancer J 2008; 14: 216–222

[39] Shamley DR, Srinanaganathan R, Weatherall R, Oskrochi R, Watson M, Ostlere S, Sugden E. Changes in shoulder muscle size and activity following treatment for breast cancer. Breast Cancer Res Treat 2007; 106: 19–27

[40] Unyo C, Chaler J, Rojas-Martinez M, Pujol E, Muller B, Garreta R, Mananas MA. A cross-sectional study comparing strength profile of dorsal and palmar flexor muscles of the wrist in epicondylitis and healthy men. Eur J Phys Rehabil Med 2013; 49: 507–515

[41] van Delden AE, Peper CE, Beek PJ, Kwakkel G. Unilateral versus bilateral upper limb exercise therapy after stroke: A systematic review. J Rehabil Med 2012; 44: 106–117

[42] van Huizum MA, Hoornweg MJ, de Ruiter N, Oudenhoven E, Hage JJ, Veeger DJ. Effect of latissimus dorsi flap breast reconstruction on the strength profile of the upper extremity. J Plast Surg Hand Surg 2016; 1–6

[43] Wang HK, Cochrane T. Mobility impairment, muscle imbalance, muscle weakness, scapular asymmetry and shoulder injury in elite volleyball athletes. J Sports Med Phys Fitness 2001; 41: 403–410

[44] Winters-Stone KM, Dobek J, Bennett JA, Nail LM, Leo MC, Schwartz A. The effect of resistance training on muscle strength and physical function in older, postmenopausal breast cancer survivors: A randomized controlled trial. J Cancer Surviv 2012; 6: 189–199

[45] Winters-Stone KM, Dobek J, Nail LM, Bennett JA, Leo MC, Torgrimson-Ojerio B, Luoh SW, Schwartz A. Impact + resistance training improves bone health and body composition in prematurely menopausal breast cancer survivors: A randomized controlled trial. Osteoporos Int 2013; 24: 1637–1646