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ORIGINAL ARTICLE

Tissue dielectric constant and circumference measurement in the follow-up of treatment-related changes in lower-limb lymphedema

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ABSTRACT

BACKGROUND: Lymphedema of lower limbs is a chronic condition that requires life-long management. Therapeutic effect of complex decongestive physiotherapy (CDP) is most often followed by circumference measurements (CM). However, the CM measurements are not specific to interstitial tissue fluid and have problems in sensitivity and objectivity. The aim of present study was to evaluate the therapeutic effect of CDP with a new tissue water specific measurement technique, in patients with lower limb lymphedema (LLL).

METHODS: A total of 17 patients with unilateral LLL (11 primary, 6 secondary lymphedema) were recruited in this study. CDP was applied for 5 days a week for 4 weeks. CM measurement of both limbs was performed at nine sites along limb by tape measure. Percentage skin water content (PWC) of thigh, calf and ankle was measured in affected lymphedema limb and contralateral limb with MoistureMeterD Compact (MMDC) device. Inter-limb PWC ratio was calculated by dividing affected side's PWC value with PWC of contralateral limb. Patients were asked to fullfill the Lymph Quality of Life Questionnaire.

RESULTS: Significant reduction of circumference after CDP was detected at all nine measurement sites along lower limb ($P<0.01$). PWC measurements showed a significant decrease of skin tissue water at thigh, calf and ankle measurement sites after CDP ($P<0.001$). Inter-limb PWC ratios demonstrated significant reduction of edema between affected and contraletral limbs post-treatment ($P<0.003$). CDP also increased the quality of life ($P=0.006$).

CONCLUSIONS: CM and PWC measurements reflected a positive effect of CDP in patients with LLL. Both absolute PWC values and inter-limb PWC ratios were meaningful tools to follow the effect of therapautic intervention. Compared with CM measurements the TDC technique offered easier, quicker, objective and more practical measurements for routine assessments of LLL.

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Key words: Lymphedema - Dielectric spectroscopy - Physical therapy modalities - Quality of life.

Chronic lymphedema is a condition as a result of dysfunctionality of lymphatic system causing visible changes in skin and accumulation of protein-rich fluid in interstitial space.[1] Primary lymphedema affecting lower limbs can manifest at any time throughout the life. Secondary lower limb lymphedema is a common consequence after pelvic cancer surgery. It was reported that individuals who undergo pelvic cancer surgery experience lower limb lymphedema (LLL) at the rate of 20-30%.[2]

Quality of life is decreased in patients with LLL. Patients experience decreased mobility, social isolation, stress, hopelessness and constraint in social relationships.[3] Decreased quality of life, self-image, decrease of self confidence, depression and anxiety have been reported in gynecologic cancer survivors with LLL.[4, 5]

Undiagnosed and untreated lymphedema might cause serious consequences.[6] Therefore, early detection and early therapy of lymphedema are of great importance

to prevent progression to a chronic condition. There are a number of methods to evaluate edema severity in extremities. These are based on metric and volume measurements, electrical impedance and commercial limb circumference techniques. The methods have advantages in simplicity but disadvantages in sensitivity and specificity.[7] Early lymphedema characterized with the accumulation of protein-rich fluid in skin and subcutis cannot always be diagnosed with these methods. Therefore, localized, objective, easy and quick evaluation tools are needed for early detection of lymphedema in superficial tissues.

The tissue dielectric constant (TDC) technique offers a possibility to trace early changes of lymphedema. Depending on the applied TDC instrument the method provides measurement of tissue water content at effective penetration depths ranging from 0.5 to 5.0 mm with a coaxial line reflection technique at 300 MHz. The 300-MHz signal is generated in the control unit and then guided via a coaxial line to the probe in contact with skin. The reflected electromagnetic wave is then processed in the control unit to calculate tissue dielectric constant of the measurement site. Vacuum and pure water have dielectric constants 1 and 78.5 at room temperature, respectively. Thus the TDC scale ranges from 1 to 80.[8]

TDC technique has been used for detecting changes in tissue water content in skin and subcutis. The interclass coefficient in lower limb measurement has been reported to be high.[8-10] Most TDC studies have been conducted in patients with upper limb lymphedema.[8, 11, 12] Only few studies are related to the follow-up of effect of lymphedema treatment in lower limbs.[9, 13]

The TDC method may offer advantages for therapeutic practice if one can easily detect the sites of edema and follow effects of applied therapy practically at all body sites.[8, 11, 13] Evaluation of treatment effects without appropriate tools might lead to biased treatment effects.[14] Thus, this study was aimed at evaluating treatment effects of LLL with TDC method.

Materials and methods

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Ethical approval was granted from the the Social Sciences Ethics Committee of Abant Izzet Baysal University ("Investigation of the Relationship Between Lymphedema Severity and Kinesiophobia," protocol no. 2015/150, 09-12-2015). Informed consent was obtained from all individual participants included in the study.

Patients were recruited from lymphedema outpatient clinic in Abant Izzet Baysal University School of Physical Therapy and Rehabilitation, Bolu, Turkey. Patients who met inclusion criteria (male or female with unilateral LLL, age 18-75 years) were invited to participate in this study. Of 31 patients fulfilling inclusion criteria six patients were excluded because of bilateral lymphedema, three patients because of active infection, three patients living far from the hospital, one patient refused to be recruited and one patient had heart surgery during recruitment. The study then included 17 patients. Power analysis was conducted for 80% power yielding to a sample size of 15 participants. Sample size calculation was done using G*Power v. 3.1.[15]

Of 17 recruited patients, 14 were females and 3 males. Eleven patients had a primary LLL, 6 had a secondary LLL. According to International Society of Lymphology classification majorirty of patients (82.3%) were belonging to grades 2 or 3. Duration of lymphedema varied from immediate onset to more than 10 years post-surgery.

Assessments related to quality of life

Quality of life was evaluated using the Lymph Quality of Life Questionnaire (LYMQOL), which is considered a valid and reliable disease specific tool consisting of questions on symptoms, body image/appearance, function and mode, respectively.[16] Altogether the LYMQOL questionnaire has 26 questions. Each question should be answered "not at all," "a little," "quite a bit," and "a lot." Higher points of LYMQOL indicates worse quality of life while lower points indicate good quality of life. General quality of life measurement was done with LYMQOL-VAS questionnaire with a scale ranging from zero to ten. Patients were asked to fill questionnaire for grading his/her general quality of life. Increased points indicated better general quality of life while decrease indicated worsening of general quality of life.

Physical measurements

Circumference measurement

CM measurement was conducted with a Leg-o-Meter apparatus.[17] A non-elastic tape measure was used. Nine reference points were marked on limb's skin with a soft pen. These points were head of metatarcal bone (R1), heel (R2), ankle (R3), distal beginning point of calf muscle (R4), middle point of calf muscle (R5), head of fibula (R6), middle line between knee and ankle (R7), middle point of the quadriceps femoris muscle (R8) and groin (R9). Circumference of affected lymphedema limb and non-affected healthy limb were measured. Distance between levels of CM measurements was recorded for post-treatment measurements.

TDC measurement

TDC measurement was performed with MoistureMeterD Compact device (MMDC, Delfin Technologies, Kuopio, Finland). The MMDC is a portable device with an integrated probe. A high-frequency electromagnetic (EM) wave generated by the device is guided into skin by placing the probe in contact with skin. Since the effective depth of measurement is 2.5 mm,[8] the device is mainly assessing the amount of tissue water in skin where lymphedema is thought to manifest initially. Skin water molecules are rotating in an EM field and absorbing energy from the field. Thus, the MMDC is spesific to the amount of tissue water. The reflected wave contains information of the energy absoption, *i.e*. the amount of water molecules in skin. Achieved TDC values were converted automatically to the PWC values by device's software. Patients were resting on an examination table for 10 minutes in a supine position. During this time, information was given on the measurement. Three measurement sites in both lower limbs free from visible creams or lotions were marked with a soft pen. The measurement sites were 20 cm proximally (thigh) and 20 cm distally (calf) from midline of the knee joint and 5 cm proximally to medial malleolus (ankle). The MMDC has a force sensor to ensure that the contact pressure of device against skin is the same for all measurements. Audible signal after measurement informs that the measurement is finished. TDC measurements were done triplicate bilaterally at each site and measurement data transferred wirelessly to a computer. Time of one measurement was approximately 3 seconds. Thus, triplicate measurements of one site took for 15 seconds.

Inter-limb TDC ratios were calculated for each measurement site by dividing affected side's TDC value with TDC value of non-affected contralateral side. Increased TDC ratio indicates greater swelling of lymphedematous limb.[8] Patients were measured in room temperature of 25 °C.

Treatment procedure

Complex decongestive physiotherapy (CDP) concept is considered a gold standard in lymphedema management. CDP consist of manual lymph drainage (MLD), skin care, compression bandages (CB) and exercise. Initially, CDP was applied in five days a week for 4 weeks. In the second phase, compression bandages are changed with compression stockings. In our practice, MLD treatment schedule also differed in patients with primary and secondary lymphedema.

Patients with primary lymphedema had MLD scheme as follows: first neck then side of abdomen's MLD was applied with paying attention to contraindications. Suction force was intensified with breathing exercises in ductus thoracicus. Related side interinguinal and axilloinguinal anastomose pathways were facilitated in both from dorsal and ventral side. After opening the anastomose ways, MLD was applied to the swollen limb. Excessive fluid was directed to opened anastomose ways from lateral side of the leg.

Participants who have secondary lymphedema had MLD scheme as follows: same procedure with primary ones was conducted except for a few differences. Side of abdomen's MLD could not be applied beacuse of radiotherapy. Besides, interinguinal anastomose way could not be used because of the excision pelvic lymph nodes associated with the cancer surgery. The rest of procedure except for those was the same for secondary lymphedema cases, too.

After MLD, skin care was applied. Lower extremities were handled with a moisturizer of pH 5.5 followed by the simultaneous use of compression bandages and exercise. After intensive phase, individually fitted compression stocking were used.

Statistical analysis

The data were analyzed by using IBM SPSS 20.0 software (IBM Corporation, New York, USA). Descriptive data were presented as a mean and standard deviation for continuous variables. Categorical variables were presented as percent (%). Kolmogorov-Smirnov and Shapiro-Wilk (KS-SW) normality test were conducted for normality of variables. Especially SW test was used for the normality of the data because in small sample size it can give more accurate conclusion of the data. Then parametric *t*-tests were used between before treatment and after treatment periods if normality had been gained. If a normality table was not gained (SW test P<0.05), were used as Wilcoxon Signed Rank tests. Pearson correlation analysis was done to investigate the correlations. P value of lower than 0.05 was accepted as statistically significant.

Results

Mean age and mean body mass index (BMI) of patients were 51.5±15.4 years and 36.7±10.4 kg/m^2, respectively. Significant reduction was detected in PWC values measured from thigh, calf and ankle after the CDP treatment of lymphedema (P<0.001). Furthermore, significant decreased inter-limb PWC ratios between affected and contralateral healthy limb indicate a reduction of lymphedema after the CDP treatment (Table I).

TABLE I.—*Effect of complex decongestive physiotherapy on percentage tissue water content and inter-limb PWC ratios.*

	Percentage of tissue water content			P value
	Before treatment	After treatment	Decrease (%)	
Ankle				
Affected	48.9±11.3	31.7±7.7	35.2	<0.001
Contralateral	41.9±8.6	41.7±8.8	0.5	NS
Calf				
Affected	53.4±10.7	34.3±7.2	35.7	<0.001
Contralateral	41.1±9.8	41.0±9.8	0.2	NS
Thigh				
Affected	46.1±9.0	38.2±6.7	17.1	<0.001
Contralateral	37.4±5.6	37.0±5.9	1.1	NS
Inter-limb PWC ratio				
Ankle	1.22±0.42	0.80±0.25	34.4	<0.001
Calf	1.36±0.43	0.88±0.2	35.3	<0.001
Thigh	1.28±0.42	1.06±0.26	17.2	0.003

PWC: percentage of tissue water content; NS: not significant (P<0.05, paired *t*-test).

CDP reduced lower limb circumference significantly at each measurement sites R1-R9 along the lower limb (P<0.05) (Table II). Reduction was greatest (17.5%) at calf in measurement site R4.

Correlations between reductions in PWC and circumference measurements at thigh, calf and ankle were statistically significant (Table III). Highest correlation between the PWC and CM parameters was detected in calf (r=0.71, P=0.002).

Effect of CDP improved quality of life significantly as assessed by LYMQOL questionnaire (pre-post treatment: 2.3±0.7 to 2.1±0.6, P=0.006). General quality of life evaluated by LYMQOL VAS also improved (pre-post treatment: 5.2±2.1 to 7.1±2.2, P=0.003).

Discussion

Present results indicate that CDP therapy was effective in patients with primary and secondary lymphedema although more than 80% of patients had grade 2 and 3 lymphedema. Effectiveness was demonstrated by the

TABLE II.—*Circumference measurements of the affected limb before and after complex decongestive physiotherapy.*

Measurement point	Before CDP (cm)	After CDP (cm)	Mean reduction (cm)	Decrease (%)	P value
R1	24.7±3.9	23.7±3.7	1.0±1.4	4	0.01
R2	34.6±4.62	32.6±3.2	2.0±2.2	5.7	0.001
R3	34.8±9.8	29.4±6.1	5.4±4.2	15.6	<0.001
R4	40.2±11	33.2±7.9	7.0±4.6	17.4	<0.001
R5	50.1±10.5	42.8±6.9	7.3±4.5	14.6	<0.001
R6	48.2±10	44.7±7.1	3.5±5.0	7.3	0.012
R7	50.6±9.2	47.2±7.8	3.4±4.4	6.7	0.006
R8	65.0±9.8	62.7±9	2.3±3.6	3.5	0.019
R9	72.4±9.5	70.4±9.3	2.0±3.0	2.8	0.01

Paired *t*-test.
CDP: complex decongestive physiotherapy.

TABLE III.—*Correlations between reductions of lymphedema in thigh, calf and ankle of affected limb assessed by PWC and circumference values.*

PWC	Circumference measurement					
	Ankle		Calf		Thigh	
	r	P value	r	P value	r	P value
Thigh	–	–	–	–	0.58	0.014
Calf	–	–	0.71	0.002	–	–
Ankle	0.58	0.014	–	–	–	–

r: Pearson's correlation coefficient; PWC: percentage of tissue water content. P<0.05.

reduction of limb circumference and skin tissue water content and questionnaires reflecting improved quality of life.

CM measurement is the most often applied method to evaluate lymphedema since it is non-invasive, cheap, easily repeatable and can also be used for volume calculation of limbs. Czerniec *et al.* considered CM measurement a reliable method for evaluating lymphedema and found a high correlation with perometer in the assessment of limb volume.[18] CM measurements from ankle, calf and thigh have assisted grading of LLL.[19] In the present study, CM measurements were performed at nine different levels of lower limb and three additional sites considered representative for thigh, calf and ankle. After treatment with CDP, significant reductions in circumference were observed at each measurement sites and highest reduction in circumference at calf.

The TDC technique is a localized quantitative method to measure skin tissue water. Since TDC value is directly proportional to tissue water content, there is a formula to convert TDC values in device display into percentage tissue water content PWC values.[8, 20] The TDC technique has several advantages for routine clinical practice since the measurements are noninvasive and no special electrodes or consumables are needed. For large-volume clinical practice, the fast and easy measurements and their wireless data transmission to computer a real advantage.

Recently, the TDC method was found to be almost five times more sensitive than bioimpedance spectroscopy in the detection of early lymphedema in breast cancer patients.[21] According to Tuppurainen *et al.*, the sensitivity of TDC method was 5.5-fold compared with circumference measurement in the assessment of LLL after gynecological cancer surgery.[22] Recently, Mayrovitz *et al.*[23] reported similar results showing that TDC method was about 3.1-14.7 times more sensitive than the bioimpedance or arm volume measurement in the preclinical detection of arm lymphedema after breast cancer treatments. Furthermore, Mayrovitz *et al.*[13] reported that TDC method was more sensitive than circumference measurement in detecting skin tissue water after manual lymphatic drainage (MLD) for LLL CM and TDC measurements before and after one MLD session showed that TDC decreased 9.8% while reduction in circumference was 1.5%.

Recently, there has been a trend to use inter-limb TDC or PWC ratios to illustrate the difference between affected and contralateral healthy limb.[8, 12] Accordingly, Mayrovitz *et al.*[12] found that inter-arm TDC ratio of 1.20 differentiated breast cancer patients with lymphedema and healthy volunteers. Since most of the TDC studies are related to upper extremity lymphedema, there are only few studies related to LLL or inter-limb TDC or PWC ratios differentiating lymphedema limbs from healthy limbs. As far as we know the present study is the first to evaluate the PWC inter-limb ratio in LLL. Pre-treatment inter-limb PWC ratios were 1.22 for ankle, 1.36 for calf and 1.28 for thigh measurement sites. Post-treatment ratios were all less than 1.20 strongly suggesting that absolute PWC values and inter-limb PWC ratios exceeding 1.20 can be recommended for health care professionals to assess severity of lymphedema at different levels of lower limbs.

Lymphedema can significantly reduce quality of life of cancer survivors. Keeley *et al.* reported that evaluation of quality of life is an important tool in the assessment of chronic edema and treatment-related factors.[24] Evaluation of quality of life was considered important in patients with LLL after CDP,[25] although it has also been critiziced to be insensitive to detect changes in the general health of a patient.[26] This study showed that complex decongestive therapy increased the quality of life (QOL) of patients with LLL.

Conclusions

CM and PWC measurements were shown to be useful in the assesment of CDP in patients with lower limb lymphedema. Greatest reductions in both parameters were found in calf and ankle measurement sites. However, there is a need for a reliable alternative to CM measuments since the method is not practical for lower limb measurements in patients lying in supine position. The currect results proved that the TDC technique with PWC display is quick, easy and objective tool to follow the effect of CDP in LLL.

References

1. Armer JM. The problem of post-breast cancer lymphedema: impact and measurement issues. Cancer Invest 2005;23:76-83.
2. Tiwari P, Coriddi M, Salani R, Povoski SP. Breast and gynecologic cancer-related extremity lymphedema: a review of diagnostic modalities and management options. World J Surg Oncol 2013;11:237.

3. Finnane A, Hayes SC, Obermair A, Janda M. Quality of life of women with lower-limb lymphedema following gynecological cancer. Expert Rev Pharmacoecon Outcomes Res 2011;11:287-97.
4. Jager G, Doller W, Roth R. Quality-of-life and body image impairments in patients with lymphedema. Lymphology 2006;39:193-200.
5. Wenzel L. Patient-reported outcomes in sentinel lymph node procedure versus inguinofemoral lymphadenectomy—What is the next step? Gynecologic oncology 2009;113:299.
6. 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;4:424-47.
7. Mayrovitz HN, Sims N, Macdonald J. Assessment of limb volume by manual and automated methods in patients with limb edema or lymphedema. Adv Skin Wound Care 2000;13:272-6.
8. Mayrovitz HN. Assessing Free and Bound Water in Skin at 300 MHz Using Tissue Dielectric Constant Measurements with the MoistureMeterD. In: Greene AK, Slavin SA, Brorson H. Lymphedema: Presentation, Diagnosis, and Treatment. Cham: Springer International Publishing; 2015. p. 133-48.
9. Birkballe S, Jensen MR, Nørregaard S, Gottrup F, Karlsmark T. Can tissue dielectric constant measurement aid in differentiating lymphoedema from lipoedema in women with swollen legs? British Journal of Dermatology 2014;170:96-102.
10. Jensen MR, Birkballe S, Nørregaard S, Karlsmark T. Validity and interobserver agreement of lower extremity local tissue water measurements in healthy women using tissue dielectric constant. Clinical physiology and functional imaging 2012;32:317-22.
11. Mayrovitz HN. Assessing local tissue edema in postmastectomy lymphedema. Lymphology 2007;40:87-94.
12. Mayrovitz HN, Weingrad D, Davey S. Tissue dielectric constant (TDC) measurements as a means of characterizing localized tissue water in arms of women with and without breast cancer treatment related lymphedema. Lymphology 2014;47:142-50.
13. Mayrovitz HN, Davey S, Shapiro E. Localized tissue water changes accompanying one manual lymphatic drainage (MLD) therapy session assessed by changes in tissue dielectric constant inpatients with lower extremity lymphedema. Lymphology 2008;41:87-92.
14. Iuchi T, Dai M, Sanada H, Okuwa M, Nakatani T, Sugama J. Associations between the treatments and outcomes of patients with upper and lower lymphoedema in Japan: A cross-sectional observational study. International journal of nursing studies 2015;52:913-9.
15. Faul F, Erdfelder E, Lang AG, Buchner A. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav Res Methods 2007;39:175-91.
16. Keeley V, Crooks S, Locke J, Veigas D, Riches K, Hilliam R. A quality of life measure for limb lymphoedema (LYMQOL). Journal of Lymphoedema 2010;5:26-37.
17. Berard A, Kurz X, Zuccarelli F, Ducros JJ, Abenhaim L. Reliability study of the Leg-O-Meter, an improved tape measure device, in patients with chronic venous insufficiency of the leg. VEINES Group. (Venous Insufficiency Epidemiologic and Economic Study). Angiology 1998;49:169-73.
18. Czerniec SA, Ward LC, Refshauge KM, Beith J, Lee MJ, York S, *et al.* Assessment of breast cancer-related arm lymphedema--comparison of physical measurement methods and self-report. Cancer Invest 2010;28:54-62.
19. Carlson JW, Kauderer J, Walker JL, Gold MA, O'Malley D, Tuller E, *et al.* A randomized phase III trial of VH fibrin sealant to reduce lymphedema after inguinal lymph node dissection: a Gynecologic Oncology Group study. Gynecol Oncol 2008;110:76-82.
20. Nuutinen J, Ikaheimo R, Lahtinen T. Validation of a new dielectric device to assess changes of tissue water in skin and subcutaneous fat. Physiol Meas 2004;25:447-54.
21. Lahtinen T, Seppala J, Viren T, Johansson K. Experimental and Analytical Comparisons of Tissue Dielectric Constant (TDC) and Bioimpedance Spectroscopy (BIS) in Assessment of Early Arm Lymphedema in Breast Cancer Patients after Axillary Surgery and Radiotherapy. Lymphat Res Biol 2015;13:176-85.
22. Cronbach LJ. Coefficient alpha and the internal structure of tests. psychometrika 1951;16:297-334.
23. Mayrovitz HN, Weingrad DN, Lopez L. Patterns of temporal changes in tissue dielectric constant as indices of localized skin water changes in women treated for breast cancer: a pilot study. Lymphatic research and biology 2015;13:20-32.
24. Keeley V. Quality of life assessment tools in chronic oedema. Br J Community Nurs 2008;13:S22-7.
25. Kim S, Yi C, Kwon O. Effect of Complex Decongestive Therapy and the Quality of Life in Breast Cancer Patients with Unilateral Lymphedema. Lymphology 2007;40:143-51.
26. Morgan PA, Franks PJ, Moffatt CJ. Health-related quality of life with lymphoedema: a review of the literature. Int Wound J 2005;2:47-62.

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