Negative pressure therapy in the management of lymphoedema

Frederick Hulme Gott, Kathleen Ly, Neil Piller and Andrea Mangion

Key words

Endermologie®, lymphoedema, negative pressure massage therapy, negative pressure wound therapy, PhysioTouch®

Frederick Hulme Gott is Physiotherapist and Medical Student, Flinders University of South Australia, Australia; Kathleen Ly is Medical Student, Flinders University of South Australia, Australia; Neil Piller is Professor of Lymphology and Director Lymphoedema Research Unit, Flinders University of South Australia, Australia; Andrea Mangion is Lecturer and Lymphoedema Physiotherapist, ALERT Education, Macquarie University, Sydney, Australia

Declaration of interest: Andrea Mangion works as a Clinical Consultant for Garnet Medical, the distributor of PhysioTouch Negative Pressure in Australia.

Abstract

Lymphoedema involves chronic tissue inflammation with tissue changes that include extracellular free fluid accumulation, tissue fibrosis and fatty tissue deposition (Zampell, 2012). Despite the best efforts of modern conservative lymphatic therapy, some patients will progress to develop significant secondary tissue changes with morbidity evident via recurrent bouts of cellulitis, reduced function and lowered quality of life. Fatty tissue deposition can continue to such severity that litres of accumulated fatty tissue warrant surgical management via liposuction (Brorson, 2006). Non-invasive and painless technology should, therefore, be of interest to lymphatic therapists aiming to improve the outcomes of conservative lymphatic therapy. Historically, conservative lymphatic therapy treatments have consisted of treatments that predominate via offering positive pressure; a pushing force onto the tissues. Compression bandaging, pressure garments, including wraps and chip bags, and massage, including manual lymphatic drainage and pneumatic compression devices, represent examples of positive pressure therapy and technology. Negative pressure, on the other hand, is a newer means of offering treatment, whereby a pulling or opening force is applied to the tissues. Treatment can be targeted to specific areas, such as areas of radiation induced fibrosis and scar tissue, or the technology can be used as an adjunct to massage and manual lymphatic drainage. Brands such as LymphaTouch® (LymphaTouch Inc.) and Endermologie® (LPG) are examples of negative pressure massage devices designed for use by manual therapists. This article introduces the concept of negative pressure technology to lymphoedema management and the proposed mechanics of action.

Conservative lymphatic therapy (CLT) is used by manual therapists as a means of treating, or reducing the risk of developing, lymphoedema (Lymphoedema Framework, 2006). It is called 'conservative' as it is usually performed by manual therapists, such as physiotherapists, occupational therapists and registered nurses, who can implement hands-on non-invasive methods of treatment. Treatment aims to manage the condition and avoid patients requiring invasive procedures, such as liposuction or tissue debulking.

There are several methods of therapy used in CLT, with the two therapy types that encompass most techniques and technology including positive and negative pressure. Historically, CLT treatments have predominated via treatments that offer positive pressure. Positive pressure modalities include any treatment that exerts a pushing force onto the tissues whereby external tissue pressure becomes higher than internal tissue pressure. Studies have shown that mechanically this results in decreased lymphatic load through reduced oedema formation following compression of blood vessels causing decreased venous pressure (Wolff et al, 2011). The recent improved descriptions of the Revised Starling's principle reinforce that the lymphatics are responsible for reabsorption of tissue fluid, with both arterial and venous blood vessels being biased towards filtration (Levick and Michel, 2010). If blood capillary filtration forces are reduced then lymphatic load will be reduced (Levick and Michel, 2010). Compression bandaging, pressure garments, including wraps and chip bags, massage including fascial releases and manual lymphatic drainage, pneumatic compression devices and exercise are examples of positive pressure technology, or therapy, that aims to directly or indirectly impact the lymphatics by positive pressure forces. Exercise for example, indirectly offers a positive pressure force through muscular contraction and increased arterial pulsation resulting in compression of lymphatic vessels (Olszewski and Engeset, 1980).

Negative pressure on the other hand, representing an advancement in CLT treatment capability, works by the opposite means to positive pressure whereby a pulling or opening force is applied to the tissues. The technology aims to make local external tissue pressure lower than internal tissue pressure and, therefore, offers a treatment that a manual therapists hands alone cannot deliver.

Negative pressure technology types

Kinesiological tape, deep breathing, cupping and medical negative pressure devices, are examples of negative pressure technology or therapies that aim to directly or indirectly impact the lymphatics by utilising negative pressure forces.

Kinesiology taping is an example of technology whereby the mechanics of action are not well understood. It is theorised that negative pressure is created indirectly through tissue movement creating skin stretch from adhesive tape pulling on the skin. As superficial tissues are pulled, more space is created between the dermis and fascia, pulling on lymphatic anchor capillaries, which attach the skin and drawing fluid into superficial lymphatic vessels. Further research is required to demonstrate the benefit in lymphoedema management, however, a small sample group study showed promising results (Malicka et al, 2014).

Deep breathing is another example of a therapy that aims indirectly to create a central negative pressure force on the lymphatic system. Changes in intra-abdominal pressure create negative pressure within the thoracic duct. Within the literature deep breathing and simple exercise alone has been shown to reduce arm lymphoedema volume and is generally regarded as a standard component of CLT (Moseley et al, 2005).

Cupping is the primitive form of local negative pressure devices, being used in Chinese alternative medicine since the second century AD and continuing to be used in contemporary Chinese medicine (Iblher and Stark, 2007). The level of negative pressure at the tissue interface cannot be controlled accurately and as bruising and swelling is a common side effect of this modality, cupping is not used to treat lymphoedema due to the risk of further harm. A 2014 case study by Al-Reefy and Parsa Nezhad reported a case of secondary arm lymphoedema occurring in a client post-breast cancer following a session of wet cupping. The authors state that the aim of the case study was to "alert other physicians about the possible side effects of cupping therapy if used in the wrong setting" (Al-Reefy and Parsa Nezhad, 2014).

There are two main types of medical negative pressure devices available for healthcare professionals: negative pressure wound therapy (NPWT) and negative pressure massage therapy (NPMT). Both will be explored further in regards to the context of their application to the lymphatic system.

Negative pressure wound therapy

NPWT devices are designed for use on open skin and chronic wounds. NPWT systems are widely used across the world with hundreds of randomised controlled trials demonstrating their efficacy in the healing of wounds and surgical incisions (Hyldig et al, 2016). The NPWT systems include a negative pressure unit, a means of creating a tissue seal (through wound care products, such as gauze material or other dressings covered by a film drape) with tubing and canisters to capture wound bed fluid.

Brands such as KCI's V.A.C® therapy or Smith & Nephew's Renasys® range, are well known within Australian public hospitals. Traditionally, the systems were exclusively used in hospital settings due to cost and practical limitations, however, more portable systems have been developed. Smith and Nephew's PICO® system is an example of portable NPWT via a disposable single-patient use unit. The system is canister free and includes a silicon based wound care product with a transparent top film layer to create the tissue seal and a battery operated negative pressure unit that lasts up to 7 days (Payne and Edwards, 2014).

Excluding the local wound care dressing, the evidence-based rationale behind the effects of negative pressure in NPWT include suction causing improved local dermal blood flow through affecting vasomotor mediators, decreased wound bed oedema by encouraging lymphatic drainage and assistance with wound bed closure through drawing the wound bed borders closer together (Hasan et al, 2015).

NPWT has not been studied greatly as part of CLT. This is probably due, in part, to the fact that wounds are not a common sequalae of lymphoedema, unless trauma is involved or a comorbid diagnosis of venous insufficiency exists. Healing of traumatic injuries in patients with chronic lymphoedema, however, is often delayed. Wollina and colleagues in 2010 described how they used topical negative pressure to promote wound healing in two cases of chronic lymphoedema. Pain and prevention of re-infection were highlighted as positive treatment outcomes (Wollina et al, 2010). In 2017, Grandalski et al used NPWT in conjunction with compression bandaging to assist with healing an ulcer of a patient with primary lower-limb lymphoedema. Of interest to note with this case was that the ulceration was caused by compression bandaging, which resulted in weeks of hospital care, suggesting that standard CLT positive pressure modalities are not without risk (Gradalski et al, 2017).

When CLT fails, invasive surgical debulking treatments, involving skin and tissue removal, have been investigated. The surgery often has poor outcomes due to poor wound healing and scar tissue formation. NPWT has been shown to improve surgical outcomes and graft uptake. Stokes et al (2006) investigated six men following penoscrotal lymphatic elephantiasis who underwent penile shaft degloving and reduction scrotoplasty, followed by transplantation of a split-thickness skin graft to the penile shaft. NPWT was shown to be safe and efficacious in bolstering the graft uptake (Stokes, 2006). Van der Walt and colleagues in 2009 examined NPWT in eight patients with severe primary lymphoedema who underwent a modified Charles procedure: usually an aggressive operation only indicated for severe lymphoedema as it often yields an unpredictable outcome. NPWT was used after the initial debulking surgery with the authors reporting that the negative pressure allowed for greater predictability of the result of the Charles procedure (van der Walt et al, 2009).

NPWT may also however have a role post initial lymphatic surgery in decreasing lymphoedema incidence though improved wound healing. In 2013, Tauber et al compared standard wound care to NPWT post-inguinal lymph node dissection and investigated rates of common lymphatic problems following this surgery. Patients treated with NPWT had significantly fewer lymphatic complications, such as formation of lymphoceles (62% versus vs. 20%), persistent lymphorrhoea (45% vs. 7%) or lymphoedema of the lower extremity (46% vs. 0%) (P=0.032) (Tauber, 2013) Further studies would be required with additional costs to treat considered.

Negative pressure massage therapy

NPMT is designed for use by manual therapists as part of CLT. The systems are differentiated to NPWT as they are designed for use on intact skin and, therefore, do not include equipment for capturing wound fluid nor are special wound dressings required. As opposed to NPWT, whereby the negative pressure can only be targeted directly over the wound bed, NPMT is ideal for use by lymphatic therapists as the therapist can determine which body areas to target the negative pressure treatment towards. Large body areas can be treated with therapy targeted directly over scars, areas of radiation induced fibrosis, fibrosis from lymphoedema, areas of oedema, around wounds or around sensitive or fragile skin areas. The units are designed for multiple patient use, which also means that they may be a more cost viable option.

The first medical NPMT device described in medical literature was LPG's Endermologie® device. Designed over 30 years ago in France, this technology is used widely in the international cosmetology market. The device uses a central vacuum unit to create the negative pressure with different patented treatment heads that include both rollers and sequential suction to mobilise tissues. A body suit, LPG endermowear®, is required to reduce the potential for skin debris being collected in to the vacuum unit.

Endermologie® (LPG) is most renowned for non-invasive fat reduction, with studies demonstrating reductions in body circumference, weight loss and body fat percentage in cosmetic medical settings (Chang et al, 1998; Kutlubay et al, 2013). Considering that fat deposition is abnormal in lymphoedema to the point whereby liposuction is now a respected medical treatment for lymphoedema, further studies are warranted on whether negative pressure could be of use to treat lymphoedema clients for non-invasive fat reduction. In small sample group studies of lymphoedema patients, when Endermologie was compared with manual lymphatic drainage, it was shown to improve treatment outcomes, decrease treatment time and improve patient satisfaction (Bacci and Leonardi, 2003; Moseley et al, 2007; Mohamed and Abol-Atta, 2011; Ahmed, 2013).

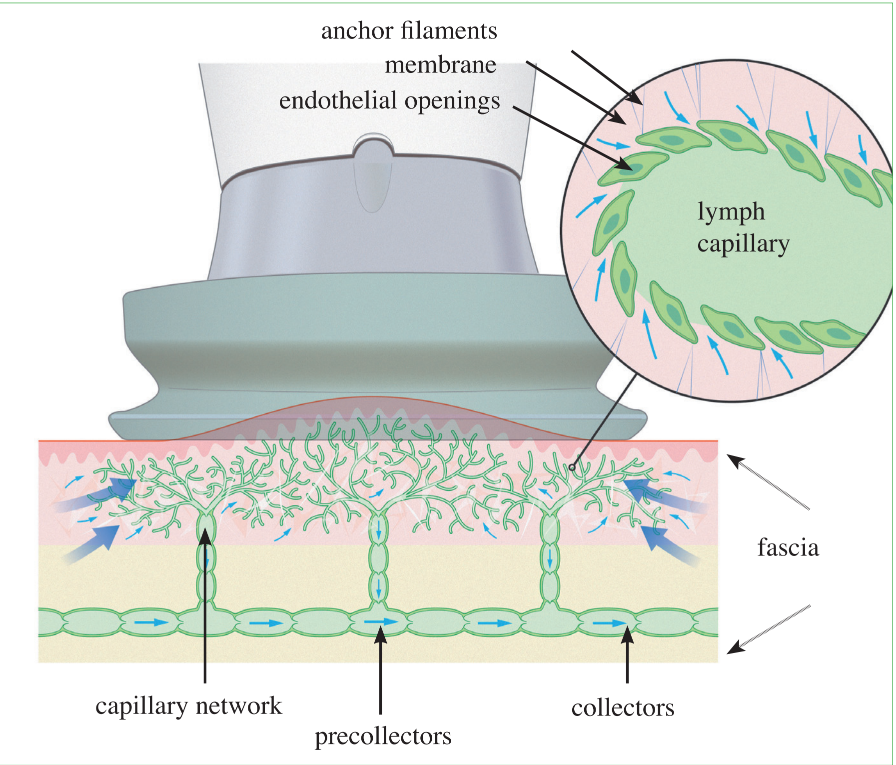

Figure 1. Illustration of the proposed effect of the LymphaTouch® device (LymphaTouch Inc.) to demonstrate the effect of negative pressure on the skin and lymphatics. Macrostrain is proposed to cause changes in external tissue pressure to distend lymphatic vessels and surrounding tissues to assist with lymphatic drainage.

Despite the international success of Endermologie in the cosmetology market, the uptake among lymphoedema therapists in Australia has been minimal. This is probably due to multiple factors, including the prohibitive cost of the units: being historically over AUD65,000 per unit, occupational noise hazard of the device, the body suit requirement, which may not fit lymphoedema clients with abnormal shaped limbs, and the inability to treat safely over bony prominences generally limiting the application to muscle belly areas. As a seal is not created on the tissues by the treatment rollers, the local level of negative pressure cannot be accurately quantified. The inability, therefore, to document the exact level of negative pressure is also a limitation of the device in regards to ensuring safety and delivering consistent and accurate medical treatment dosages.

LymphaTouch® (LymphaTouch Inc.; previously known as PhysioTouch), was a device designed for manual lymphatic therapists. Developed in Finland in 2005 and reaching the market in 2009, the portable unit of 1.2 kg is designed for use both in the clinic setting, as well as in the home. The unit includes the vacuum unit for creating the negative pressure and patented mouthpieces which create a tissue seal. The level of negative pressure can be accurately quantified at the tissue interface from 20–250 mmHg by sliding the touch screen scale with the treatment head measuring negative pressure 300 times per second (Iivarinen et al, 2013).

Bony prominences can be treated over allowing for areas such as the face, spine, elbows and knees to be treated. Skin filters are in each mouthpiece eliminating the requirement for body stockings. Occupational hazard from noise is also eliminated as an infrared sensor detects skin and only starts the device suction when in contact with skin and automatically engages negative pressure when the mouthpiece is brought close to the skin.

In small case studies in clients with lymphoedema, when compared with manual lymphatic drainage, LymphaTouch was shown to improve treatment outcomes, decrease treatment time and improve patient satisfaction (Vuorinen et al, 2013; Obsorne, 2015; Whitaker, 2015). Further randomised controlled trials are required in this area.

Mechanism of action of negative pressure

The literature on negative pressure in wound healing has informed our understanding of the two main mechanisms of action of negative pressure: macrodeformation (or macrostrain) and microdeformation (or microstrain). Macrostrain can be described as the visible movement of the tissues as seen when a negative pressure therapy (NPT) device is placed onto the tissues, whereas microstrain includes cellular and vessel tissue changes that we cannot see with the naked eye (Glass et al, 2014).

Macrostrain

Negative pressure, in the context of lymphoedema, is theorised to result in changes in transmural pressure across lymphatic vessel walls to allow for dilation or slight distention of the vessel and surrounding tissues. The contractile profile of the lymphatics have been shown to be quite sensitive to changes in mechanical loads with modulation of intraluminal pressure resulting in dynamic shifts in lymphatic pump frequency and stroke volume (Nipper and Dixon, 2011).

Under normal physiologic conditions the 'suction pressure' in collecting lymphatic vessels, manifesting as a transient drop in pressure downstream of the inlet valve following contraction, allows fluid to be drawn in through initial lymphatics (Jamalian et al, 2017). Negative pressure could, therefore, be being used to faciliate normal lymphatic system physiology by using variations in interstitial pressures to encourage flow through lymphatic vessels.

Microstrain

The concept of piezoelectricity explains how cells which produce and digest collagen fibres (fibroblasts and fibroclasts) might be responsive to electric charges. Mechanical forces from the outside creates a higher electric charge, which then stimulates the fibroblasts to increase their production rate of collagen fibres in that area (Athenstaedt, 1974). The mechanical activation response of fibroblasts has been shown to occur within minutes of tissue lengthening (Langevin, 2006).

In NPWT, microstrain is used to encourage positive cellular reactions to create a wound bed environment that is conducive for tissue repair. NPWT has been shown to induce wound bed granulation and angiogenesis through microdeformation stimulating vasculogenic growth factors (Hasan, 2015). Cellular activity of cells, such as fibroblasts and macrophages, is improved, having a positive outcome on wound healing.

In patients with lymphoedema, accumulation of interstitial and lymphatic fluid within the skin, the subcutaneous tissue and above and below muscle fascia stimulates fibroblasts, keratinocytes and adipocytes. The resulting deposition of fibrosis, collagen and glycosaminoglycans within the tissues causes tissue hypertrophy and destruction of elastic fibres (Zampell et al, 2012). The local tissue environment in the area of chronic swelling is, therefore, not conducive to local repair. Technology that can, therefore, possibly promote positive cellular activity through microstrain, therefore, warrants further investigation.

Discussion

Manual lymphatic drainage (MLD) has been considered a core clinical component of CLT, for over 20 years, assisting with psychological and symptomatic consequences of lymphoedema (Takeno et al, 2013). MLD technique, however, relies heavily on the technical skill of the therapist. Some of the reasons for the lack of efficacy of MLD have been quoted in papers as poor standardisation of the massage technique, as well as variable subjective measures of quantifying pressure applied with massage therapy (Huang et al, 2013; Stuiver et al, 2015). NPMT, via devices that can accurately quantity the level of negative pressure at the tissue interface, offers a possible solution to this through the ability to quantify the level of treatment dosage.

In chronic lymphoedema it has been demonstrated that large volumes of fluid can exist above and below the muscle fascia (Olszewski and Engeset, 2009). The mobilisation of deep fascia and epimysium requires manual treatment that generates enough pressure to reach the surface of muscles. Modalities targeting deeper structures, which would not cause additional pain or inflammation would, therefore, be ideal. In limbs that have significant lymphoedema or radiation induced fibrosis, this explains the theoretical reason why superficial massage techniques, that are designed to utilise dermal backflow to mobilise fluid through lymphatic capillaries, fail to adequately reduce limb volume. By drawing the tissues upwards with facilitation of lymphatic drainage at the same time, it could be theorised that NPMT may address pain and inflammation, while allowing for fascial mobilisation of deeper structures. Further studies would need to investigate this however.

NPMT devices may decrease therapist fatigue as the device draws the tissues upwards, rather than the therapist being required to push into the tissues. Burn out rates in professions such as physiotherapy are high and, therefore, sustainability in the workplace is a relevant consideration (Girbig et al, 2017).

MLD has traditionally been performed without gloves. NPMT method can be used without skin to skin contact, thereby reducing the potential risk of absorption of toxins from chemotherapy, radiotherapy or bodily fluid transfer. Consequently, harm that might result from skin to skin contact may be minimised.

When to intervene with the most appropriate type of force, be it positive or negative pressure or a combination of therapies, will require more research. Mihara and colleagues in 2012 showed that lymphatic vessels become sclerosed and contracted in the later stages of lymphoedema (Mihara et al, 2012). Using negative pressure with the aim to open and mobilise contracted and tight vessels seems logical. It also seems logical that compression and closure of the lymphatic vessel if a patient has primary lymphoedema with significant lymphatic vessel valvular incompetence, especially when the limb is in a gravity dependant position, would still be of value. A combination of therapies may, therefore, be appropriate.

Conclusion

NPMT offers a new and innovative method for treating lymphoedema and can potentially improve complex lymphoedema therapy outcomes. Further research needs to be conducted as this area is in its infancy.

Acknowledgements

As this article is a practice development piece, and was written predominantly by students, no funding was required for this paper.

References

Ahmed E (2013) Endermologie Technique versus Decongestive Lymphatic Therapy on Post-mastectomy Related Lymphedema. *Novel Physiotherapies* 3(3):155

Al-Reefy S, Parsa Nezhad M (2014) Lymphedema following cupping therapy Hijama Post breast cancer surgery and axilla clearance. *Bahrain Medical Bulletin* 36(1): 44–5

Athenstaedt H (1974) Pyroelectric and piezoelectric properties of vertebrates. *Ann N Y Acad Sci* 238: 68–94

Bacci PA, Leonardi S (2016) Vibro-assisted liposuction and endermologie for lipolymphedema. In: Shiffman M, Di Giuseppe A (eds) *Liposuction*. Springer, Berlin, Heidelberg

Brorson H, Ohlin K, Olsson G, Nilsson M (2006) Adipose tissue dominates chronic arm lymphedema following breast cancer: an analysis using volume rendered CT images. *Lymphat Res Biol* 4(4): 199–210

Chang P, Wiseman J, Jacoby T et al (1998) Non-invasive mechanical body contouring: (endermologie) a one year clinical outcome study update. *Aesthetic Plast Surg* 22(2): 145–53

Girbig M, Freiberg A, Deckert S et al (2017) Work-related exposures and disorders among physical therapists: experiences and beliefs of professional representatives assessed using a qualitative approach. *J Occup Med Toxicol* 12: 2

Glass GE, Murphy GF, Esmaeili A et al (2014) Systematic review of molecular mechanism of action of negative-pressure wound therapy. *Br J Surg* 101(13): 1627–36

Gradalski T, Kurpiewska J, Ochalek K, Bialon-Janusz A (2017) The application of negative pressure wound therapy combined with compression bandaging for the decubitus ulcer of an advanced primar lower limb lymphedema. *Int J Dermatol* 56(7): e144–e7

Hasan MY, Teo R, Nather A (2015) Negative pressure wound therapy for management of diabetic foot wounds: a review of the mechanism of action, clinical applications and recent developments. *Diabet Foot Ankle* 6: 27618

Huang TW, Tseng SH, Lin CC et al (2013) Effects of manual lymphatic drainage on breast cancer-related lymphedema: a systematic review and meta-analysis of randomized controlled trials. *World J Surg Oncol* 11: 15

Hyldig NH, Birke-Sorensen M, Kruse C, Vinter J et al (2016) Meta-analysis of negative-pressure wound therapy for closed surgical incisions. *Br J Surg* 103(5): 477–86

Iblher N, Stark B (2007) Cupping treatment and associated burn risk: a plastic surgeon's perspective. *J Burn Care Res* 28(2): 355–8

Iivarinen JT, Korhonen R, Julkunen P, Jurvelin JS (2013) Experimental and computational analysis of soft tissue mechanical response under negative pressure in forearm. *Skin Res Technol* 19(1): e356–65

Jamalian S, Jamalian M, Zawieja S et al (2017) Demonstration and analysis of the suction effect for pumping lymph from tissue beds at subatmospheric pressure. *Sci Rep* 7(1): 12080

Kutlubay Z, Songur A, Engin B et al (2013) An alternative treatment modality for cellulite: LPG endermologie. *J Cosmet Laser Ther* 15(5): 266–70

Langevin HM (2006) Connective tissue: a body-wide signalling network? *Med Hypotheses* 66(6): 1074–7

Levick JR, Michel CC (2010) Microvascular fluid exchange and the revised starling principle. *Cardiovasc Res* 87(2): 198–210

Lymphoedema Framework (2006) *Best Practice for the Management of Lymphoedema. International Consensus.* London: MEP Ltd. Available at: https://bit.ly/2HOpXBh (accessed 04.05.2018)

Malicka I, Rossegar A, Hanuszkiewicz J, Wozniewski M (2014) Kinesiology taping reduces lymphedema of the upper extremity in women after breast cancer treatment: a pilot study. *Prz Menopauzalny* 13(4): 221–6

Mihara M, Hara H, Araki J et al (2012) Indocyanine green (ICG) lymphography is superior to lymphoscintigraphy for diagnostic imaging of early lymphedema of the upper limbs. *PLoS One* 7(6): e38182

Mohamed FA, Abol-Atta HEM (2011) Effectiveness of endermologie technique in post mastectomy lymphedema. *Medical Journal of Cairo University* 79(2): 1–4

Moseley AL, Piller NB, Carati CJ (2005) The effect of gentle arm exercise and deep breathing on secondary arm lymphedema. *Lymphology* 38(3): 136–45

Moseley AL, Espin M, Piller NB, Douglass J (2007) Endermologie (with and without compression bandaging) -- a new treatment option for secondary arm lymphedema. *Lymphology* 40(3): 129–37

Nipper ME, Dixon JB (2011) Engineering the lymphatic system. *Cardiovasc Eng Technol* 2(4): 297–308

Osborne J (2015) *Can Early Intervention with PhysioTouch®'s Mechanical Leverage in the Functioning of Initial Lymphatic Vessels Help Promote Long Term Physiological Homeostasis as well as Fluid Volume Reduction in a Locally Impacted Lymphatic Territory.* 25th World Congress on Lymphology; San Francisco, USA. Conference presentation

Olszewski W (2009) Where do lymph and tissue fluid accumulate in lymphoedema of the lower limbs caused by obliteration of lymphatic collectors? *Lymphology* 42(3): 105–11

Olszewski W, Engeset A (1980) Intrinsic contractility of prenodal lymph vessels and lymph flow in human leg. *Am J Physiol* 239(6): 775–83

Payne C, Edwards D (2014) Application of the single use negative pressure wound therapy device (PICO) on a heterogeneous group of surgical and traumatic wounds. *Eplasty* 14: e20

Stokes TH, Follmar KE, Silverstein AD et al (2006) Use of negative-pressure dressings and split-thickness skin grafts following penile shaft reduction and reduction scrotoplasty in the management of penoscrotal elephantiasis. *Ann Plast Surg* 56(6): 649–53

Stuiver MM, Tusscher MR, Agasi-Idenburg CS et al (2015) Conservative interventions for preventing clinically detectable upper-limb lymphoedema in patients who are at risk of developing lymphoedema after breast cancer therapy. *Cochrane Database Syst Rev* 13(2): CD009765

Takeno Y, Arita H, Fujimoto E (2013) Efficacy of complete decongestive therapy (CDT) on edematous rat limb after lymphadenectomy demonstrated by real time lymphatic fluid tracing. *Springerplus* 2(1): 225

Tauber R, Schmid S, Horn T et al (2013) Inguinal lymph node dissection: epidermal vacuum therapy for prevention of wound complications. *J Plast Reconstr Aesthet Surg* 66(3): 390–6

van der Walt JC, Perks TJ, Zeeman BJ et al (2009) Modified Charles procedure using negative pressure dressings for primary lymphedema: a functional assessment. *Ann Plast Surg* 62(6): 669–75

Vuorinen VJ J Iivarinen,J, Jurvelin,K, Airaksinen, O (2013) *Lymphatic Therapy using Negative Pressure.* TEKES [the Finnish Funding Agency for Technology and Innovation]. Available at: https://bit.ly/2wclKlB (accessed 04.05.2018)

Whitaker JC (2015) *The Benefit of One Session on a Negative Pressure Device when used in a Manual Lymphatic Drainage (MLD) Sequence in Primary Lymphoedema.* 25th World Congress on Lymphology; San Francisco, USA. Conference presentation

Wolff O, Wentell TD, Reeder SWI, Neumann HAM (2011) The effect of compression ulcer stockings on the capillary filtration rate and the formation of oedema. *Phlebologie* 5: 245–90

Wollina U, Hansel G, Kronert C, Heinig B (2010) Using VAC to facilitate healing of traumatic wounds in patients with chronic lymphoedema. *J Wound Care* 19(1): 15–7

Zampell JC, Yan A, Elhadad S et al (2012) Regulation of adipogenesis by lymphatic fluid stasis: part I. Adipogenesis, fibrosis, and inflammation. *Plast Reconstr Surg* 129(4): 825–34