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Mathematical Model of the Upper Limb Manual Lymph Drainage Massage

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Abstract: This paper reports the formulation of a mathematical model that describes the manual lymph drainage massage typically employed in the treatment of upper limb lymphedema. The ability to model such massage is a key feature for the development of automated physical therapy systems that aim at mimicking and assisting the therapist. This type of mathematical model can be hardcoded into a control system responsible to control a soft exoskeleton such as an upper limb sleeve. There is currently no similar model in the literature, nor is there information available about the actual forces exerted by the occupational therapists or the massage profile. Thus, this paper provides a deeper insight into the massage process, using the upper limb lymphedema as a case study. The first step of the design process was to identify the pressure amplitudes and profiles made by the occupational therapists during the manual lymph drainage. A commercial sensorized pressure glove was used to quantitatively analyze the massage. More than 50 occupational therapists wear the sensorized pressure glove when performing an upper limb drain massage and hours of pressure profiles were recorded. The loads and time spent at each compression were characterized, and the compression spots at the upper limb were identified. With the identification of the pressure sites, the respective load and the massage speed, we propose a model capable of mathematically describing the massage profile.

Keywords: Smart Textiles, Wearable Textiles, Compression Garments, Soft Orthotic Devices, Massage, Mathematical Model

1. Introduction

The motor activation and control of human hands generate an elegant and smooth coordination of several joints in order to carry out complex dynamic tasks, such as a massage. A Manual Lymphatic Drainage (MLD) massage is performed by occupational therapists and is very different from a muscle relaxation massage that relies on deep and rigorous rubbing. MLD is much gentler and should feel as if the skin is being brushed, not rubbed or kneaded. Occupational therapists develop the empirical knowledge on how to perform a MLD massage based on their training where the applied forces, compression times and compression profiles, are practiced over years. The empirical knowledge from occupational therapists on how to perform massages is useful not only to teach others but also to develop mathematical model able to translate in numbers a MLD massage [1-4].

Along the years, the development of mathematical models to understand kinematic and force features of different massage techniques have been the research topic of several research groups. Many authors have reported investigation on human support and healthcare application of robotics and also multifingered robot hand that can be used in the treatment of muscle injuries [5, 6]. Existing massage researches mainly focus on the trajectory reproduction and the changing forces made by humans [7, 8]. The compression time and compression force variability according to the location are normally not studied.

The reproduction of movements and forces are made by combining pressure sensors with pressure actuators arranged in a close loop [9, 10]. Robotic hands and soft exoskeletons are used to embed the pressure sensors and actuators control based on a developed model [11, 12].

The pressure quantification and the profile pressure identification during a MLD are crucial to develop a mathematical model able to set the specifications for a device that could mimic an upper limb drain massage performed by occupational therapists in the treatment of the upper limb lymphedema. Upper limb lymphedema is a life time health condition characterized by an increase of the upper limb diameter due to the accumulation of interstitial fluid (lymph) at the upper limb. Most of the times, the upper limb lymphedema is a consequence of the breast cancer treatment that damage the lymphatic system [13]. Skin burns and infections can also be a cause of upper limb lymphedema [14]. Depending on the lymphedema stage, this health condition can be a source of significant pain, incapacitating patients for daily tasks such as showering, dressing, and eating [15].

In this paper, the manual lymph drainage procedure is explained based on real data collected from occupational physiotherapists. A novel mathematical model was developed with the aim to standardize a highly variable and human dependent procedure.

2. Manual Lymph Drainage

The goal of an upper limb lymphedema manual lymph drainage treatment is to move extra fluid from a swollen upper limb, into the lymph nodes located in the neck or axilla. In order to move the extra fluid into the lymphatic system, it is necessary to open the lymph nodes at first. This can be done with deep breathing exercises and stretch/release the skin around the neck and under the arm. After opening the lymph nodes, the occupational therapist can start the lymph propulsion. This lymph propulsion is done stimulating contractions of lymphatic vessels. The pressure of the hands on the skin should be just enough to gently stretch the skin as far as it naturally goes, and then release. If the occupational therapist feels the patient´s muscles underneath the fingers, it means that is pressing too hard. It is important to start the drain massage near the wrist and progressively go to spots near the shoulder. Several light compression cycles need to be done during at least 20 minutes. During the compression cycles, it is important to use the palm of the hands instead of the fingertips. This allows more contact with the skin to stimulate the lymph vessels. The massage must be done with the patients in a comfortably (seating or lying) position and in a warm environment which will allow the muscles to be more flexible.

3. Methods

The upper limb manual lymph drainage performed by the occupational therapists was studied with the aim to know the applied pressures and pressure distribution profile on the upper limb.

The 15 subjects (11 female, 4 male) who participated in this study were occupational therapists with experience performing drain massages on an upper limb lymphedema. All the subjects were recruited from a private hospital (Hospital Privado de Barcelos) that agreed with the experimental protocol. The experiment was explained to the volunteers and all of them gave a written informed consent before participate on it. Each occupational therapist performed only one upper limb drain massage into a healthy upper limb. The occupational therapists had a working experience in the 1-13 years range. When enquired about how many upper limb MLDs they perform per week, all of them answer at least two.

During the drain massage, the occupational therapist used an instrumented glove (Finger Tips Sensor-PPS) on the right hand, as shown in Figure 1. This instrumented glove has pressure sensors that record the compression profiles and the applied pressures during the massage. Before starting each drain massage, the instrumented glove was calibrated. At the calibration procedure, the subject pressed the instrumented glove against a device made by the glove supplier (PPS-Pressure Profile Systems) until achieving a pre-defined pressure (up to 7 kPa). The collected pressure data was sent in real time to computer via Bluetooth connection. The computer was running an application that not only displayed the pressure data but also saved it for off-line analysis.

Figure 1. *Instrumented glove (Finger Tips Sensor-PPS).*

4. Results

The results of the manual lymph drainage performed by the occupational physiotherapist were studied in order to understand the compression profiles applied at an upper limb. From the results, it is possible to identify a compression pattern. All the occupational therapists tend to apply pressure at five different spots, three at the lower arm and two at the upper arm (Figure 2a). The maximum pressure value at each spot increases from the wrist to the bicep as shown at Figure 2b. The compression period shown in Figure 2b is repeated during the entire time of the performed drain massages.

From the Figure 2b, it is possible to see that the light compressions made by the occupational therapists during the MLD are similar to parabolic shapes with negative concavity. The amplitude of the parabolic shapes is the maximum pressure applied at the compression spot. The maximum amount of pressure applied by each occupational therapist is different at the same compression spot when different compression periods are analyzed. The compression time is also different between the compression spots and different occupational therapist use different compression times.

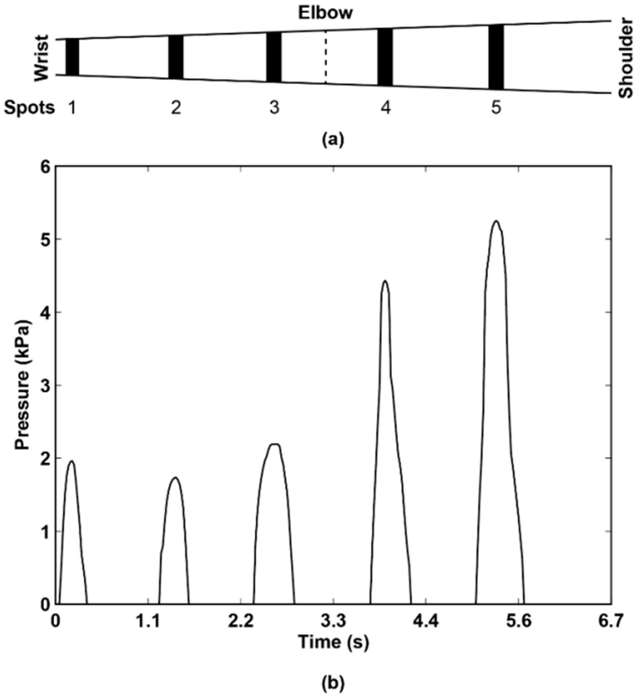

Figure 2. (a) Compression spots during a compression cycle; (b) Compression cycles performed by a physiotherapist during upper limb drain massage.

Figure 3 shows a boxplot graph with the pressure distribution at each compression spot. It is possible to see that there is a progressive average pressure applied from the wrist (compression spot 1) to the near shoulder (compression spot 5). It also shows a high variance range at each compression spot.

Table 1 shows the maximum and minimum compression values at each compression spot. The mean pressure values, the first quartile (Q1) and third quartile (Q3) are also show. Compression spot 5 has the highest variance (3.4 kPa) and the highest average pressure (5.8 kPa). The lowest variance is shown at compression spot 5 (1.3 kPa) and lowest average pressure value was verified at compression spot 1 (2.3 kPa).

The compression time duration was also studied for each compression spot in order to know if the occupational therapists tend to spend more time at a specific location. The time boxplot presented at Figure 4 shows that the average time spent at the compression spots 2-5 is similar (around 2.4 s in average) and slightly lower at compression spot 1 (1.8 s in average). There is also a high variance at each compression spot. Compression spot 1 is the compression spot with the lowest variance time (1 s) and the compression spot 2 shows the highest variance (1.7 s).

Table 1. Pressure boxplot parameters for the five compression spots (values in kPa).

	Spot 1	Spot 2	Spot 3	Spot 4	Spot 5
Min.	1.2	1.6	2.1	4.8	4.0
Q1	1.8	2.1	2.8	5.1	4.9
Mean	2.3	2.6	3.6	5.4	5.8
Q3	2.7	3.0	4.3	5.8	6.6
Max.	3.3	3.5	5.1	6.1	7.4

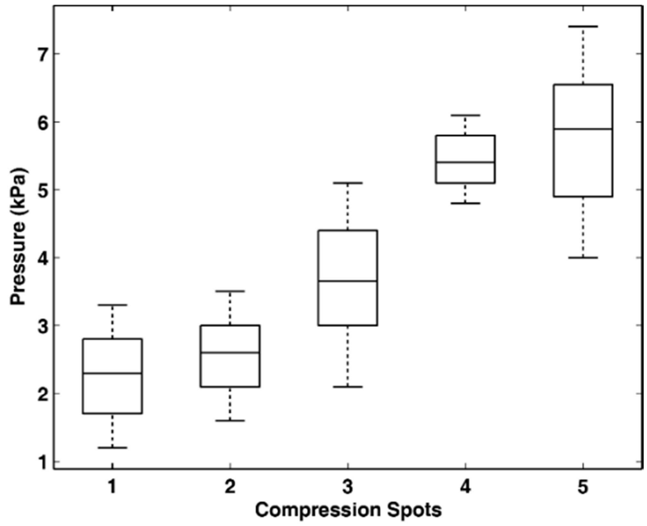

Figure 3. Pressure distribution at each compression spot during a Manual Lymph Drainage.

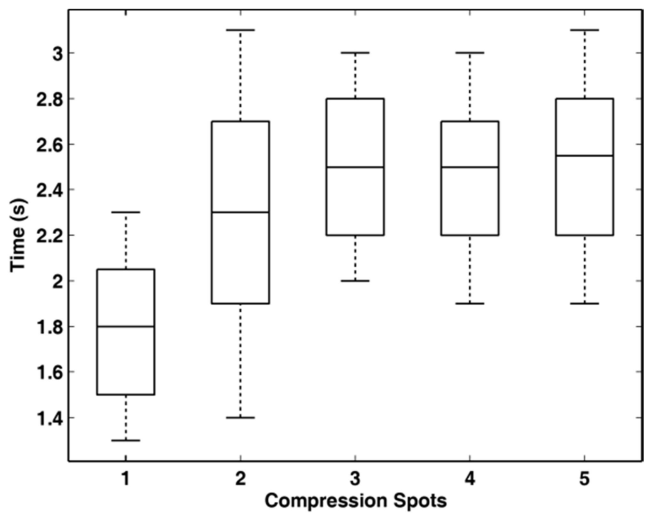

Figure 4. Time distribution of the applied pressure at each compression spot.

Table 2 shows the time parameters from the graph presented at Figure 4.

Table 2. Time boxplot parameters for the five compression spots (values in seconds).

	Spot 1	Spot 2	Spot 3	Spot 4	Spot 5
Min.	1.3	1.4	2	1.9	1.9
Q1	1.6	1.9	2.2	2.1	2.2
Mean	1.8	2.3	2.5	2.4	2.5
Q3	2.1	2.7	2.7	2.7	2.8
Max.	2.3	3.1	3.0	3.0	3.1

5. Model Development

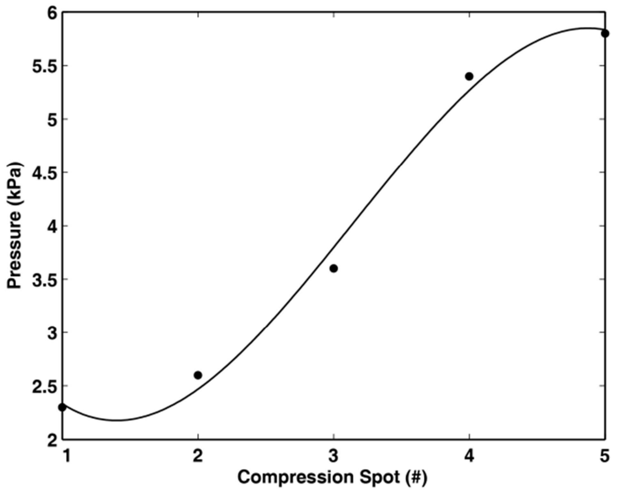

Figure 5. *Trend line of the pressure applied in the entire upper limb length during the drain massage.*

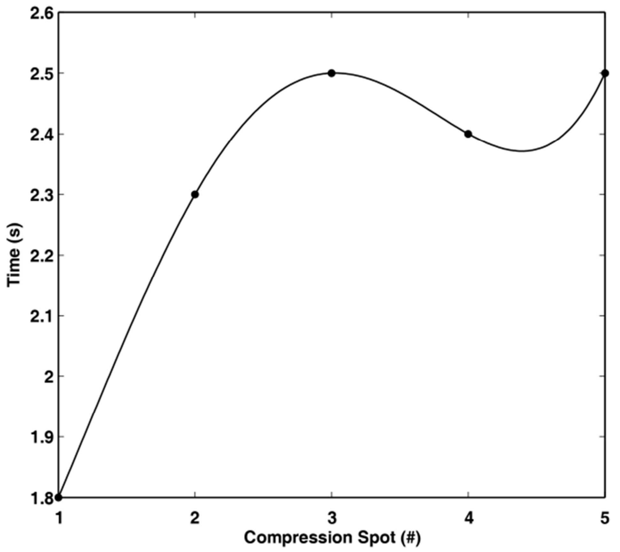

Figure 6. *Trend line of the time spent in the entire upper limb length during the drain massage.*

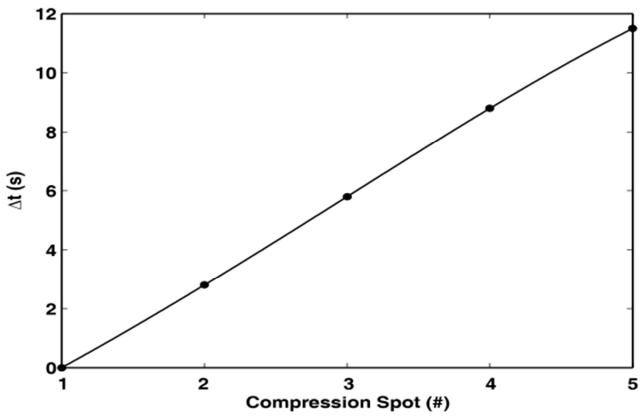

Figure 7. *Trend line of the time spent between the maximum pressure values at each compression.*

The compression profiles made by the occupational therapist have hyperbolic shape that can be divided into four phases. The first phase occurs when the occupational therapist starts the compression and it is characterized by a slowly pressure increment. After the initial segment, the pressure rapidly increases until a maximum point, which performs the second compression phase. The third phase occurs after the compression reaches the peak pressure. During the third phase the applied pressure decrease rapidly until the last compression phase. The fourth and last compression phase is characterized by a slow compression decrease until the pressure achieves a zero value.

Compression Cycle Behavior

The compression cycle behavior can be mathematically translated by the function $sin^4(x)$. With amplitude of 1, the $sin^4(x)$ allows to not only comply with the four compression moments of the compression cycle, but also meet the different pressure peaks at different time intervals. Due to the different pressure amplitudes and the different time spent at each compression moment, the pressure profile at a given time (in seconds) and for a given compression spot (k), $P\ (t,k)$, is determined by

$$P\ (t,k) = A(k).\,sin^4[j(k).\,t + i(k)] \quad (1)$$

where $A(k)$ is the maximum pressure amplitude value at the k compression spot, $j(k)$ is the compression time duration coefficient at each k compression spot, and $i(k)$ is the time delay coefficient at each k compression spot in regard to the first spot (wrist). In order to simplify the model at this moment, it is assumed that

$$k \in \{1, 2, 3, 4, 5\} \quad (2)$$

in the same manner as illustrated in Figure 2b.

Moreover, due to the repetitive nature of the $sin^4(x)$ function, it becomes important to force a zero outside of the compress site. Thus, one can rewrite eq. 1 in the following format

$$P(kt) = \begin{cases} A(k).\,sin^4[j(k).\,t + i(k)] & ,i(k) < t < i(k) + j(k) \\ 0 & ,i(k) \geq t \geq i(k) + j(k) \end{cases} \quad (3)$$

With the average pressure values from each compression spot (k), it is possible to do a trend line that provides the pressure distribution at the upper limb length. Figure 5 shows the trend pressure line resulting from the average pressure values from the massage along the upper limb. The trend line shown at Figure 5 can be represented by Equation 4 with a coefficient of determination (R^2) of 0.99.

$$A(k) = -0.175k^3 + 1.6464k^2 - 3.5786k + 4.44 \quad (4)$$

The expression resulted in a maximum deviation from the real values in less than 5.5% (at compression spot #3).

Compression Pulse

The time spent to compress is different for the same compression spot, and it is also different between compression spots (k). The average compression time at each compression spot can be used to build a trend line that can be modulated by a mathematical function. Figure 6 shows the trend line of the time spent to do the upper limb drain massage throughout the upper limb. It can be represented by Equation 5 with a coefficient of determination (R^2) of 1.

$$j'(k) = 0.0208x^4 - 0.2083x^3 + 0.5792x^2 - 0.0917x + 1.5 \quad (5)$$

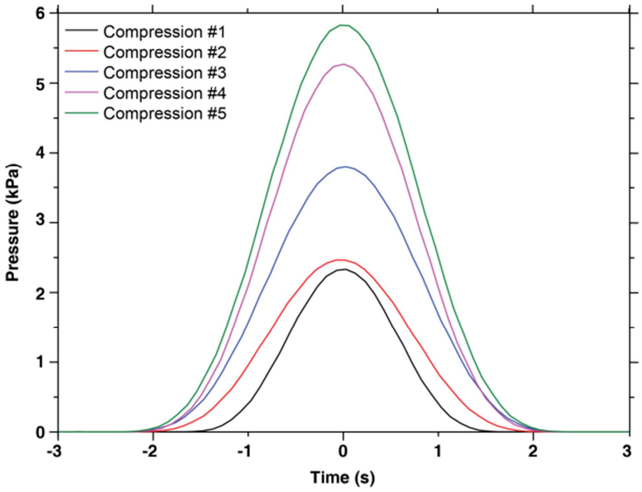

Figure 8. *Different compression profiles at each compression spot considered in the analysis.*

With such R^2 value, as expected the obtained deviation error was 0.64%. In order to normalize the time domain within the $sin^4(x)$ function, it becomes necessary to divide the x variable by the time period, thus

$$j(k) = 1/j'(k) \quad (6)$$

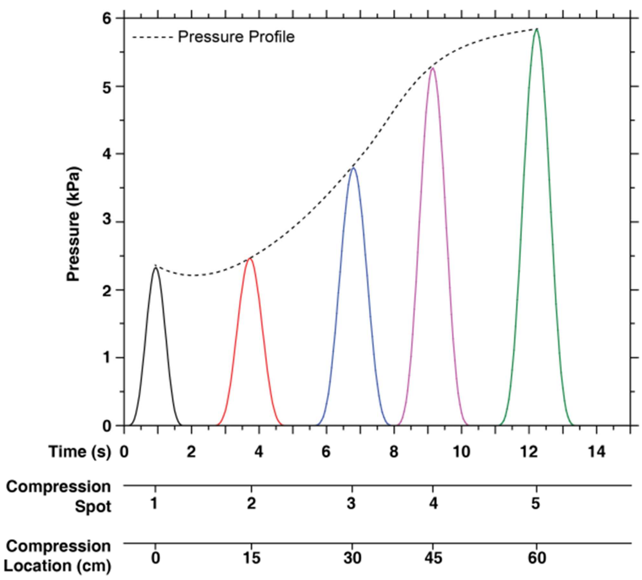

Figure 9. *Instant applied pressure and pressure duration into an upper limb during manual lymph drainage.*

Compression Delay

The time delay between the maximum pressure values at two followed compressions is different depending on the compression spots. Figure 7 shows a trend line for the average time spent between a given compression and the first one (in compression site 1). It can be represented by Equation 7 with a coefficient of determination (R^2) of 0.99.

$$i(k) = 2.9x - 2.92 \quad (7)$$

Model Demonstration

Although the model was built based on $sin^4(x)$ function, in order to translate the rad domain into the time domain (in seconds) the x variable needs to be multiplied by π, thus equation 1 takes this final form

$$P(t,k) = A(k).sin^4[(j(k).t + i(k)).\pi] \quad (8)$$

With the mathematical model developed, it is possible to visualize the differences between the different compression patterns (Figure 8). As one can see, as the massage is driven up the arm, the compression pressure increases as well as the compression cycle period.

Although the model considered only 5 compression spots as an approach to simplify its definition, these spots can be translated to locations in the arm, by translating the spot in length suing the following equation

$$Length\ (cm) = 15.k - 15 \quad (9)$$

The current model, as it is, is limited to a maximum length of the arm of 60 cm, but it can be normalized to expand such length to other arm lengths (shorter of longer). In Figure 9, it becomes possible to visualize the wave (massage) propagation along the arm.

6. Conclusions and Future Work

The mathematical systematization of the upper limb manual lymph drainage performed by occupational therapist allows understanding deeply the pressures and compression profiles of this treatment technique. With this work the empirical knowledge of the occupational therapists is translated into a mathematical model that can help them standardize the performed treatment. At the same time the mathematical model can open research avenues with the aim to enhance the treatment of the upper limb lymphedema. Moreover this work proves that it is possible to find patterns of high empiric treatments like an upper limb drain massage perform by occupational therapists. Those patterns can be modelled into a mathematical model and guide the development of devices tailored to help in the treatment of upper limb lymphedema patients.

Future work will focus on using the acquired information about the manual lymph drainage to select sensors and actuators that can best mimic the massage made by the occupational therapists.

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References

[1] Hu, L., et al., *A massage robot based on Chinese massage therapy.* Industrial Robot: An International Journal, 2013. 40 (2): p. 158-172.

[2] Rattanaphan, S. and P. Srichandr, *Mechanical Model of Traditional Thai Massage for Integrated Healthcare.* Journal of healthcare engineering, 2015. 6 (2): p. 193-212.

[3] Wang, J. and Y. Li. *Massaging human feet by a redundant manipulator equipped with a tactile sensor*. in *Advanced Intelligent Mechatronics (AIM), 2010 IEEE/ASME International Conference on*. 2010. IEEE.

[4] Xiaoqin, Y. and X. Yonggen. *Design and simulation of Chinese massage robot based on parallel mechanism*. in *Mechanic Automation and Control Engineering (MACE), 2010 International Conference on*. 2010. IEEE.

[5] Minyong, P., et al. *Expert massage motion control by multi-fingered robot hand.* in *Intelligent Robots and Systems, 2003. (IROS 2003). Proceedings. 2003 IEEE/RSJ International Conference on*. 2003. IEEE.

[6] Terashima, K., et al., *Modeling and massage control of human skin muscle by using multi-fingered robot hand.* Integrated Computer-Aided Engineering, 2006. 13 (3): p. 233-248.

[7] Luo, R. C. and C. C. Chang. *Electromyographic signal integrated robot hand control for massage therapy applications*. in *Intelligent Robots and Systems (IROS), 2010 IEEE/RSJ International Conference on*. 2010. IEEE.

[8] Wei, Y., et al., *Strategies for feet massage robot to position the pelma acupoints with model predictive and real-time optimization.* International Journal of Control, Automation and Systems, 2016. 14 (2): p. 628-636.

[9] Tian, L., et al., *The making of a 3D-printed, cable-driven, single-model, lightweight humanoid robotic hand.* Frontiers in Robotics and AI, 2017. 4: p. 65.

[10] Wang, W., et al., *The force control and path planning of electromagnetic induction-based massage robot.* Technology and Health Care, 2017. 25 (S1): p. 275-285.

[11] Della Santina, C., et al. *Estimating contact forces from postural measures in a class of under-actuated robotic hands*. in *Intelligent Robots and Systems (IROS), 2017 IEEE/RSJ International Conference on*. 2017. IEEE.

[12] Luo, R. C., C.-W. Hsu, and S.-Y. Chen. *Control and Analysis of a Therapeutic Massage Robot: A Milestone of Human-Robot in Physical Contact*. in *ISR 2016: 47st International Symposium on Robotics; Proceedings of.* 2016. VDE.

[13] Damstra, R. J., *Upper Limb Lymphedema*, in *Lymphedema*. 2011, Springer. p. 287-293.

[14] Edgar, D. W., M. Fear, and F. M. Wood, *A Descriptive Study of the Temporal Patterns of Volume and Contents Change in Human Acute Burn Edema: Application in Evidence-Based Intervention and Research Design.* Journal of Burn Care & Research, 2016. 37 (5): p. 293-304.

[15] Sagen, A., et al., *Upper limb physical function and adverse effects after breast cancer surgery: a prospective 2.5-year follow-up study and preoperative measures.* Archives of physical medicine and rehabilitation, 2014. 95 (5): p. 875-881.