Understanding normal seasonal variations in upper-limb size, volume and fluid distribution in a healthy female population: a North Queensland study

Authors (clockwork from top left):
Melanie Matthews, Sue Gordon, Susan Witt and Neil Piller

This study set out to determine whether or not variations in upper limb arm size, volume or fluid distribution occur in response to heat and humidity, as it varies with the seasons in healthy females. Data collection took place in spring, summer and winter, with results showing a significant relationship between seasonal climate variation and limb size, with significant decreases in summer and winter when compared to spring. No relationship was found between seasonal climate variation and limb volume or fluid distribution. This study also describes normal variation in limb size with seasonal change in a tropical environment. This provides baseline data for future research comparing the effect of seasonal change in at-risk populations, such as those with lymphoedema and vascular conditions.

Melanie Matthews is** Physiotherapist, Wesley Mission Queensland, Sinnamon Village Aged Care Community, Australia;* ***Sue Gordon *is Professor, Caring Futures Institute, Flinders University & Associate Professor, James Cook University, Townsville, Queensland, Australia;* ***Susan Witt*** *is Occupational Therapist and PhD Candidate, Lymphoedema Clinical Research Unit, Flinders University, Australia;* ***Neil Piller*** *is Director Lymphoedema Clinical Research Unit, Flinders University, Australia*

Anecdotally, people report swelling of their limbs during hot and humid weather. However, little is understood about variation in limb size, volume and fluid distribution in normal populations related to changes in weather. Numerous physiological changes occur in response to environmental exposure. Heat and humidity can cause increased cardiac output and skin temperature, increased sweat responses, dehydration, changes in blood and body fluid properties and impaired motor coordination (Koulmann et al, 2000; Garzon-Villalba et al, 2017; Piil et al, 2020).

When relative humidity levels are high, sweating responses are ineffective due to impaired evaporation of sweat, as skin moisture levels are similar to the ambient environment (Che Muhamed et al, 2016). Such a change in thermoregulation can lead to overheating and dehydration. Extreme heat can lead to death, especially in vulnerable populations (Conti et al, 2005; Kenny et al, 2018). Some studies focusing on heat acclimatisation and exercise saw a major increase in plasma levels (Kenny et al, 2018).

Similar, but less marked responses have been shown to occur merely due to exposure to hot environments. Physiological changes stabilise within 14 days of exposure to an altered environment (Kenny et al, 2018). An increase in plasma, in turn, increases extra-cellular fluid levels, which may impact on limb size and fluid distribution within the limb. Furthermore, heat exposure has shown to increase blood flow to the peripheries (Taylor, 2014).

One study has investigated the relationship between upper-limb swelling, heat and humidity in a population of 17 women without lymphoedema and 25 women with secondary lymphoedema following breast cancer treatment (Czerniec et al, 2016). Results from this study found that there were no significant links between variables in the population without lymphoedema, however, notes that Sydney, Australia, where this research occurred, has a temperate climate and results of this study may, therefore, not be applicable to women living in climates that have greater range and extremes of temperature.

In the lymphoedematous population, there was statistically significant correlation between average maximum temperatures and measures of the affected limb. Average humidity was found to have no effect on the lymphoedematous population.

To date, no research has investigated the effect of seasonal climate variation on upper-limb size, volume and fluid distribution in a healthy population living in tropical climates. This study investigated upper-limb variations in relation to seasonal climate variation, in tropical North Queensland. Healthy women aged over 40 years were recruited to mimic a population at risk of developing secondary lymphoedema following breast cancer treatment. This research was undertaken to contribute to the understanding of the body's response to heat and humidity, to define normal variation in limb size, volume and fluid distribution in a tropical environment and to assist in defining what should be considered an abnormal response.

Methodology

Participants

Following approval from the James Cook University (JCU) Human Ethics Committee (H3480), participants were recruited from the JCU and Anne Street Gospel Chapel communities, and through snowball sampling. Participants were included if they were women aged over 40 years and able to provide consent. Participants were excluded if they had: a history of upper limb or neck injury; breast cancer; lymphoedema; a pacemaker or were pregnant. These criteria were chosen to ensure the recruitment of a healthy population whose age was comparable to that of a population affected by secondary lymphoedema following breast cancer treatment and to ensure participant safety with Bioelectrical Impedance Analysis (BIA). Sixty-three participated in the first data collection and 56 participated on all occasions. All participants were residents of Townsville, Queensland. The mean age of participants was 55 years and 3 months, with ages ranging from 40 years and 3 months to 81 years and 10 months.

Anthropometric measures

Any weight gain, through muscle or adiposity, will alter upper-limb composition and upper-limb circumferences, therefore, participant anthropometric measures were collected at each measurement session. Height, weight, waist circumference and buttock circumferences were recorded to identify any change in overall body shape and size.

Preliminary study

Ten healthy participants were recruited for an intra-measurer reliability study of upper-limb circumferential measurements. This established that the primary investigator (MM) who was responsible for all circumferential measurements had an intra-class correlation coefficient of >0.85 for all incremental and anatomical landmark circumferential measures.

Limb size and volume

The Australasian Lymphology Association (ALA) provides a comprehensive methodology for circumferential measurements of the upper limb (Koelmeyer et al, 2004) which was used to measure gross limb size. Upper-limb circumferential measures performed at anatomical landmarks were summated to quantify limb size and are known as the Sum of Anatomical Circumferences (SOAC).

Circumferential measures taken at incremental points along the limb were also used to calculate limb volume using frustum and cylinder formulae. The frustum formula assumes the arm to be the shape of a truncated cone, whereas the cylinder formula assumes the arm to be a cylindrical shape. The formulas use the circumferences at the distal and proximal aspect of the limb segment to calculate a volume. Taylor et al (2006) found volumes (frustum) calculated using anatomical landmarks to be more accurate, reliable and valid than those calculated from incremental measures from the fingertips. Both measures were used in this study.

Bioelectrical impedance analysis

Bioelectrical Impedance Analysis (BIA) is a non-invasive, painless and highly specific technique that directly quantifies fluid distribution through identifying changes in extracellular fluid (ECF) within a person's limb (Cornish et al, 1996). The time taken for the current to flow through the limb reflects the resistance, or impedance levels of the limb to each of the currents. Each limb is measured individually to eliminate the impact of trunk volume (Organ et al, 1994). BIA was performed on both upper limbs using an ImpediMed ImpTM SFB37.

Climate and discomfort

Thom's Discomfort Index, proposed in 1959, uses average maximum temperature, relative humidity and an empirical formula to comment on subjective experiences of comfort and discomfort in a variety of environmental conditions (Angouridakis and Makrogiannis,

Table 1. Changes in individual measures across occasions of measurement.

	Spring	Summer	Winter	Spring to summer	Spring to winter
	Mean (SD)	Mean (SD)	Mean (SD)	*P*-value	*P*-value
MCP (ND)	19.16 (0.97)	18.90 (1.01)	18.84 (0.93	0.000	0.000
MCP (D)	19.52 (0.94)	19.25 (0.91)	19.20 (0.93)	0.000	0.000
US (ND)	16.01 (1.03)	15.88 (1.11)	15.79 (1.03)	0.002	0.000
US (D)	16.21 (1.00)	16.10 (1.06)	16.09 (1.03)	0.017	0.003
OLEC (D)	25.68 (2.12)	25.49 (2.17)	25.55 (2.27)	0.010	0.158
Acrom (ND)	42.49 (4.25)	40.13 (4.19)	40.03 (4.20)	0.000	0.000
Acrom (D)	43.00 (4.46)	40.00 (4.44)	40.24 (4.17)	0.000	0.000

Table 1. Mean and standard deviation values for all measures, in spring, summer and winter and corresponding *P*-values.

	Spring	Summer	Winter	Multivariate ANOVA
	Mean (SD)	Mean (SD)	Mean (SD)	*P*-value
SOAC (ND)	103.14 (7.46)	100.26 (7.65)	99.92 (7.53)	0.000
SOAC (D)	104.40 (7.58)	100.83 (7.85)	101.24 (7.70)	0.000
Frustum (ND)	2016.19 (444.95)	2022.25 (437.03)	1521.14 (273.12)	0.387
Frustum (D)	2036.25 (437.03)	2022.25 (449.03)	2039.64 (449.77)	0.663
Cylinder (ND)	2010.88 (442.85)	2016.48 (446.49)	2008.10 (451.45)	0.787
Cylinder (D)	2030.91 (434.94)	2037.77 (440.78)	2034.24 (447.50)	0.875
Bioelectrical impedance (ND)	2.75 (0.63)	2.68 (0.70)	2.87 (0.37)	1.370
Bioelectrical impedance (D)	2.56 (0.57)	2.57 (0.64)	2.73 (0.37)	0.621

Table 3. Qualitative reports of heaviness and swelling in arms.

	Spring	Summer	Winter
	n (%)	*n* (%)	*n* (%)
Heavy arms	3 (4.76)	5 (8.19)	1 (1.78)
Swollen arms	5 (7.9)	5 (8.19)	4 (7.14)

1982; Paliatsos and Nastos, 1999; Vouterakos et al, 2012). The Discomfort Index scores are then grouped into four categories:

- No discomfort
- Less than half the population feels discomfort
- More than half the population feels discomfort
- Most of the population feels discomfort.

This research was undertaken in Townsville, Queensland, Australia. The climate of Townsville is tropical with hot, wet Summers and warm, dry Winters. Relative humidity usually remains above 50% year-round (Bureau of Meteorology, 2010). Thom's Discomfort Index was deemed the most appropriate representation of seasonal climate variation as data was readily accessible, and it encompassed factors relevant to Townsville weather — both heat, and humidity. Three points of data collection were deemed sufficient to represent seasonal climate variation.

Data collection

Data collection was undertaken in October 2009 (spring); February 2010 (summer) and June 2010 (winter). Measures were taken in a systematic order of height, weight, bioelectrical impedance, upper-limb circumferential measures and finally, waist and buttock circumferences. Additionally, participants completed a questionnaire at each occasion of measurement regarding self-perceptions of limb heaviness or swelling, fluid, food and alcohol consumption prior to measurements and recent physical activity undertaken. All data collection was conducted by the principal researcher (MM).

Data analysis

Data were manually recorded and entered into an Excel spreadsheet. All data entry was checked by an independent assistant. Data were analysed using PASW Statistics (SPSS Version 18) and Microsoft Excel. All limb measures were grouped and analysed according to limb dominance. A Multi-variance Analysis of Variance for Repeated Measures (MANOVA) was undertaken for each of the following variables to establish if significant change occurred across the occasions of measurement: individual circumferential measures, SOAC, frustum and cylinder volumes, impedance ratios, BMI and waist-to-buttock ratios. If MANOVA identified significant differences across the three data points used and sphericity assumptions held, appropriate paired t-tests or Wilcoxon tests were undertaken. *P*-values of less than 0.05 were considered significant.

Results

The anthropometric descriptors of participants in this study remained stable throughout this study. Therefore, any change in arm size cannot be attributed to an overall change in body weight.

There was a significant increase in size of both the dominant and non-dominant upper limb using SOAC in spring. Most individual anatomical circumferences were significantly larger in Spring when compared to other seasonal data points *[Table 1]*. No significant change in limb volume was identified using frustum or cylinder formulae or fluid distribution, represented by the impedance ratio. Mean, standard deviations and multivariate ANOVA *P*-values for limb size, limb volume and fluid distribution for each measurement session are presented in *Table 2*. Overall, qualitative symptom reports of upper-limb heaviness were greater in the summer, but swelling was similarly reported (7–8%) across all seasons *[Table 3]*.

Discussion

Gross upper-limb size as measured by the Sum of Anatomical Circumferences was significantly greater in spring compared with Summer and Winter. Anomalies were that the dominant olecranon measure only showed significant change from spring to summer and no significant change was identified for the non-dominant olecranon measure.

In all cases, the significant change was a decrease in circumference in relation to the spring measure. Interestingly, there was a perceived increase in heaviness of limbs in summer compared to spring and winter, despite the objective measures not reflecting this. This may be due to human heat adaptation as reflected by Kenny et al (2018), including sweating, increased skin temperature and activity awareness, where the body responds to changes in environment to ensure continued healthy functioning. Populations with impaired body functioning, such as lymphatic insufficiency, also report an exacerbation of arm swelling during the summer months (Phillips, 2011; Czerniec et al, 2016). Those at risk of, or with secondary upper-limb lymphoedema are advised to avoid exposure to extreme cold or heat (Lymphoedema Framework, 2006; Nielsen et al, 2017) or hot environments, such as hot showers, saunas and sun exposure (Cancer Research UK, 2020), to decrease the risk of developing or increasing lymphoedema symptoms.

Potentially confounding variables were controlled by using a standardised protocol for participant preparation prior to and during the measurement sessions. Through controlling confounding variables such as hydration, physical activity and time of day of measurement, the remaining potential causes for change are likely to be related to the influence of heat and humidity. Further, no significant changes in the anthropometric descriptors of BMI or waist-to-buttock ratio were identified. This indicates that the overall distribution of adiposity and overall heaviness of the sample population remained stable across time. As such, changes in upper-limb size are not likely to be attributable to a change in body size. Significant differences existed across seasons when individual measures were summated (SOAC). For some individual measures, however, the actual numerical differences in mean circumference were small. This change is not likely to impact on quality of life or function in a healthy population.

Maximum temperature, relative humidity and Thom's Discomfort Index were calculated for the 14 days preceding measurement sessions. These are provided to represent time in which acclimatisation can occur and for each day of data collection. The majority of the days preceding data collection and actual days of measurement, fell within the predicted Thom's Index range. As the variations that did occur were not present for more than 14 days, it is unlikely that physiological changes occurred. It was, therefore, appropriate to include all days of data collection in the analysis.

The Thom's Discomfort Index, while providing an index of discomfort due to heat and humidity, does not allow consideration of temperature and humidity separately. For example, a score of 26 for the Thom's Index could be obtained if the temperature is 34 degrees, with 25% humidity, or with a temperature of 28 degrees and 75% humidity. The lowest levels of humidity correlated to the data point at which SOAC measures and individual circumferential measures taken at anatomical and incremental landmarks increased (spring). Accordingly, the change in SOAC could also be linked to high temperatures and moderate levels of humidity.

Study strengths, shortcomings and recommendations

The strengths of this study were that the calculated sample size was surpassed, retention was high and, where applicable, most confounding variables were controlled. Attempts to standardise the time and day of measurement sessions were mostly successful and using a written measurement protocol throughout data collection assisted in methodological consistency. Additionally, a preliminary inter-measurer reliability study showed that the researcher had good reliability of circumferential measures taken at both incremental and anatomical landmarks, suitable for clinical use.

The skills required for taking reliable upper-limb circumferential measures include consistency in participant and limb position and accuracy in the palpation of anatomical landmarks and use of the tape measure. A change in any of these variables across time will alter circumferential measures. Considering that the spring measures were the first data point, the changes identified may be attributed to refining each of these components.

The questionnaire asked participants if they had experienced swelling or heaviness in their arms in the last three months. Overall, reporting of swelling and heaviness increased in summer. Verbal discussions during data collection times, suggested a higher number of participants experiencing these feelings in their hands, but did not consider this as part of their arm when providing a response on the questionnaire. In addition, the questionnaire did not ask participants to comment on time spent in air-conditioned environments, which may potentially impact exposure to climatic variation.

The study by Czerniec et al (2016) showed average maximum temperature to significantly alter limb measures in a population affected by upper-limb lymphoedema. Currently, it is unknown if the same responses occur in areas of different climates. This gap provides justification for future research into limb size, limb volume and fluid distribution in a population with lymphoedema.

To further support the current study, future studies could be undertaken with a healthy population of males, or in a cohort of different age demographics. Using two clinicians to take all measures would allow the tracking inter-measurer measures across time. Expanding this study across locations with different seasonal climate variation would provide a broader view on the normal responses to heat and humidity.

Conclusion

In a healthy population of women living in Townsville, significant differences in limb size were identified, with the Sum of the Anatomical Circumferences being significantly greater in spring than during summer and winter. Also, most circumferential measures at anatomical landmarks were greater in spring. This change may identify that limb size increases when the climate is of high temperatures and moderate levels of humidity or could be attributed to an alteration in measurement technique as the researcher refined data collection skills.

No significant changes in limb volume or fluid distribution were identified when compared across three different discomfort levels according to the Thom's Discomfort Index. Future research investigating a variety of healthy populations and populations with lymphoedema will contribute to a greater understanding of the effect of seasonal climate variation of upper-limb size, volume and fluid distribution. WINT

Conflict of interest

The authors declare that they have no competing interests.

Authors' contributions

MM was the primary researcher and submitted the original research report in partial fulfillment of the requirements of the degree of Bachelor of Physiotherapy with Honours with James Cook University in 2010, SW updated the report and prepared for publication, SG and NP provided supervisory input.

Acknowledgements

- Professor Dr Susan Gordon for support throughout this project. For providing guidance, comment and encouragement
- Helen Land for allowing the use of James Cook University Physiotherapy Clinic to undertake the data collection
- The Anne Street Gospel Chapel community for the use of the hall for data collection
- Claire Ferguson and Wendy Lawrence for assisting in the data recording process
- Petra Buettner and Gary Williams for providing support with statistical analysis
- The World Health Organisation Collaborating Centre for Lymphatic Filariasis for the use of the Bioelectrical Impedance Analysis machine
- ImpediMed, for donating electrodes
- The participants, without whom this research would not have been possible.

References

Angouridakis VE, Makrogiannis TJ (1982) The Discomfort-Index in Thessaloniki, Greece. *Int J Biometeor* 26: 53–9

Bureau of Meteorology (2010e) *Townsville, Queensland: Monthly Climate Statistics, All years of Record*. Available at: https://bit.ly/3tP0KL5 (accessed 23.04.2021)

Cancer Research UK (2020) *Lymphoedema after Breast Cancer Treatment*. Cancer Research UK. Available: https://bit.ly/2PPg6AI (accessed 12.04.2021)

Che Muhamed AM, Atkins K, Stannard SR et al (2016) The effects of a systematic increase in relative humidity on thermoregulatory and circulatory responses during prolonged running exercise in the heat. *Temperature (Austin)* 3(3): 455–64

Conti S, Meli P, Minelli G et al (2005) Epidemiologic study of mortality during the Summer 2003 heat wave in Italy. *Environmental Res* 98(3): 390–9

Cornish B, Bunce I, Ward L et al (1996) Bioelectrical impedance for monitoring the efficacy of lymphoedema treatment programmes. *Breast Cancer Res Treat* 38(2): 169–76

Czerniec SA, Ward LC, Kilbreath SL (2016) Breast Cancer-Related Arm Lymphedema: Fluctuation over Six Months and the Effect of the Weather. *Lymphat Res Biol* 14(3): 148–55

Garzon-Villalba XP, Wu Y, Ashley CD, Bernard TE (2017) Ability to Discriminate Between Sustainable and Unsustainable Heat Stress Exposures-Part 2: Physiological Indicators. *Ann Work Expo Health* 61(6): 621–32

Kenny GP, Wilson TE, Flouris AD, Fujii N (2018) Heat exhaustion. *Handb Clin Neurol* 157: 505–29

Koulmann N, Jimenez C, Regal D et al (2000) Use of bioelectrical impedance analysis to estimate body fluid compartments after acute variations of the body hydration level. *Med Sci Sports Exerc* 32(4): 857–64

Lymphoedema Framework (2006) *Best Practice for the Management of Lymphoedema*. *An International Consensus*. London: MEP Ltd. Available at: https://bit.ly/2Qos9EH (accessed 13.04.2021)

Nielsen I, Gordon SJ, Selby S (2017) Breast cancer-related lymphoedema risk reduction advice: a challenge for health professionals. *Cancer Treat Rev* 34(7): 621–8

Organ LW, Bradham GB, Gore DT, Lozier SL (1994) Segmental bioelectrical impedance analysis: theory and application of a new technique. *J Appl Physiol (1985)* 77(1): 98–112

Paliatsos AG, Nastos PT (1999) Relation between air pollution episodes and discomfort index in the greater Athens area, Greece. *Global Nest Journal* 1(2): 91–7

Phillips J (2011) *The Effect of Climate on Upper Limb Size, Volume, Fluid Distribution and Diagnostic Classification Following Breast Cancer Treatment*. (Physiotherapy Research report submitted in partial fulfilment of the requirements of the degree of Bachelor of Physiotherapy with Honours). James Cook University, Townsville.

Piil JF, Christiansen L, Morris NB et al (2020) Direct exposure of the head to solar heat radiation impairs motor-cognitive performance. *Sci Rep* 10(1): 7812

Taylor N (2014) Human heat adaptation. *Compr Physiol* 4(1): 325–65

Taylor R, Jayasinghe,U, Koelmeyer L et al (2006) Reliability and Validity of Arm Volume Measurements for Assessment of Lymphedema. *Phys Ther* 86(2): 205–14

Vouterakos P, Moustris K, Bartzokas A et al (2012) Forecasting the discomfort levels within the greater Athens area, Greece using artificial neural networks and multiple criteria analysis. *Theoretical and Applied Climatology* 110: 329–43