Intra- and inter-rater reliability of lower leg waterplethysmography, bioelectrical impedance and muscle twitch force for the use in standing work evaluation

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Intra- and inter-rater reliability of lower leg waterplethysmography, bioelectrical impedance and muscle twitch force for the use in standing work evaluation

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Received 16 June 2016, revised 20 February 2017
Accepted for publication 15 March 2017
Published 3 April 2017

Abstract

Objectives. Prolonged standing is associated with multiple risk factors for musculoskeletal and venous disorders. In Germany over 50% of the working population spend most of their working time in a standing position. Basic understanding of prolonged standing physiology is lacking. We therefore plan to investigate the influence of 5 h standing (including breaks) on lower limb oedema measured by waterplethysmography (WP) and bioelectrical impedance (BI) and fatigue in the triceps surae muscle using muscle twitch force (MTF). In order to interpret our results, test-retest and inter-rater reliability of these measurement methods was evaluated first.

Approach. 20 subjects (9 female) were included to test each method three times (M1, M2, M3) in 30 min periods with two raters (R1, R2) on separate days. Intraclass correlation coefficient (ICC; 2,1), standard error of measurement (SEM) and smallest real difference (SRD) were calculated for both raters.

Main results. The SEM and SRD calculated for WP were 27 and 75 ml, respectively, for R1 and 23 and 64 ml, respectively, for R2 with an ICC of 0.98 ($p < 0.0001$). Statistically significant mean differences between M1 and M2 (R1 = 23 ml, $p = 0.004$; R2 = 19 ml, $p = 0.027$) but not significant mean differences between M2 and M3 (R1 = -6 ml, $p = 0.45$; R2 = 4 ml, $p = 0.27$) were calculated for both raters. BI data revealed SEM and SRD values of 3.8 and 10.5 $\Omega$, respectively, for R1 and 3.4 and 9.4 $\Omega$, respectively, for R2 with an ICC of 0.98 ($p < 0.0001$). The differences between M1 and M2 (R1 = 3.9 $\Omega$, $p = 0.0001$; R2 = 2.4 $\Omega$, $p = 0.049$) and between M2 and M3 (R1 = 2.3 $\Omega$, $p = 0.012$; R2 = 2.0 $\Omega$, $p = 0.008$) were found to be statistically significant for both raters. SEM and SRD for MTF were 0.19 and 0.53 N, respectively, for
R1 and 0.23 and 0.64 N, respectively, for R2 with an ICC of 0.71 (p < 0.0001). Mean differences between M1 and M2 were statistically significant for rater 1 but not for rater 2 (R1 = 0.13 N, p = 0.022; R2 = 0.12 N, p = 0.082) and the same was found for the difference between M2 and M3 for both raters (R1 = 0.04 N, p = 0.37; R2 = 0.08 N, p = 0.12). Significance. All three measurement methods showed good reliability and should be suitable for detecting effects of standing work on oedema development and fatigue as seen in previous results of long term standing experiments. Inter-rater reliability is found to be satisfactory as well, demonstrated by the small differences in SEM values of R1 and R2. Statistically significant differences shown for all three measurement methods could be due to lacking standardisation of leg placement and thus an actual lower leg volume change between measurements, indicating possibilities for further improvement of SEM values.

Keywords: waterplethysmography, bioelectrical impedance, muscle twitch force, reliability, standing work, lower leg

(Some figures may appear in colour only in the online journal)

Introduction

Prolonged standing is associated with multiple musculoskeletal disorders (MSDs) of the lower limbs and lower back region (Andersen et al 2007, Pensri et al 2009, Werner et al 2010) as well as venous diseases like varicosis or chronic venous insufficiency (Tüchsen et al 2000, Bahk et al 2012). Thus, work-related exposure to standing has been found to increase the risk for developing these disorders (McCulloch 2002). Studies have shown that even short time exposure to static standing can induce muscle fatigue and lower leg swelling, which are discussed as being indicators of an increased risk for MSDs and venous disorders (Atsumi et al 1987, Ganasegeran et al 2014, Ringheim et al 2015). A survey by the German Federal Institute for Occupational Safety and Health (Bundesanstalt für Arbeitsschutz und Arbeitsmedizin—BAuA) underlines the high prevalence of standing work in Germany, 54.7% of employees surveyed indicated that they often work in a standing position (Wittig et al 2013). In addition, international publications on prevalence of standing work show similar results for their respective labour forces (Krijnen et al 1997, Tissot et al 2005).

As already mentioned, muscle fatigue and lower leg swelling are regarded as important surrogate parameters of an increased risk for MSDs and venous disorders during standing work. In previous studies addressing health risks due to occupational standing, multiple methods to measure muscle fatigue and lower leg swelling were used (Tomei et al 1999, Andersen et al 2007).

Swelling—lower leg volume

Waterplethysmography (WP) is a method to measure lower leg volume (LLV) by water displacement. It is regarded as the gold standard of volumetry (Petersen et al 1999, Henschke et al 2006). Measurement error has been reported to be between 0.1 and 1.0% depending on experimental setup and execution (Rabe et al 2010). The water tank used for the present research covers a large part of the lower leg (more than 40 cm from plantar), increasing the amount of displaced water compared to setups described in previous studies (Rabe et al 2010), therefore possibly increasing measurement error. The disadvantages of this procedure...
include the time consuming steps of filling the tank with water, placing the subject’s leg into the tank, draining the water and then refilling the tank again, making it challenging to use in a field setting.

Bioelectrical impedance (BI) measurement can also be used as a method for evaluating volume changes in human limbs (Kanai et al 1983, Seo et al 1995, Seo et al 2001). It is an indirect approach whereby a low intensity constant electrical current is applied to a subject’s limb, and surface electrodes measure the resulting voltage. This can be used as a relative estimate for changes in liquid distribution, which are related to a change in limb volume (Kanai et al 1983, Kanai et al 1988). A reduction of BI (lower voltage compared to baseline) corresponds to an increase of LLV and vice versa. At measuring frequencies below 1 kHz, current flows mainly through extra-cellular fluid due to the high impedance of cell membranes according to the Cole model (Cole 1972, Kanai et al 1987, Jaffrin and Morel 2008). This method has a significant time advantage compared to WP and may therefore be used as an alternative if reliability can be assured.

**Muscle fatigue**


The aim of the present study was to investigate the intraday test-retest reliability and the inter-rater reliability of two methods to quantify changes in lower leg volume as an indication of lower leg swelling (WP and BI) and one method to determine the amount of muscle fatigue (MTF). Knowledge about test–retest and inter-rater reliability is crucial for the selection of suitable methods and for the interpretation of changes in lower leg oedema and/or muscle fatigue caused by working in a standing position.

**Methods**

**Subjects**

20 healthy subjects (9 women and 11 men, age: 26.6 ± 7.1 years; height: 174.9 ± 8.8 cm; weight: 68.2 ± 11.6 kg) were recruited to participate in the present study. Exclusion criteria were severe venous diseases, age under 18 or over 67, and medication including diuretics, venotonics, vasodilators or antihypertensive drugs. The study was approved by the local ethics committee of the Medical Faculty, University of Tuebingen. All subjects signed informed consent prior to investigations and received financial compensation for their participation.

**Raters**

Both raters were experienced in conducting all three measurement procedures. Prior to this study rater 1 and rater 2 had carried out more than 50–100 measurement procedures within the past 9 months for WP, BI and MTF.
Measurement procedures

Lower leg volume.

Waterplethysmography. For WP measurement, a water tank of 50 cm height (water tap at 40 cm), 19 cm width and 36 cm length was used. An overflow valve (water tap 1/2-inch diameter) was installed at the height of 40 cm to purge the water displaced by the leg. Before the measurement was conducted, the tank was filled above level of the closed overflow valve with regular tap water (temperature: 25–30 °C). Then the valve was opened until the water level dropped down to the level of the outlet. The valve was closed when less than 1 drop per 10 s flowed out of it. In order to lower the water surface tension, which could impair water flow from the tank, a few drops of a detergent (surfactants) were added. Then the subject’s lower leg was inserted into the tank carefully. Two scales, one on the bottom of the tank and a second one with an adjustable rubber band to monitor the subject’s knee position at the upper side of the tank, were used to individually standardize and document an upright position of subject’s lower leg (see figure 1). Subjects were advised to keep contact with the bottom of the tank with the entire sole of their foot without putting load on it and to keep contact to the rubber band with their knee. Chair position and height were set individually to avoid any contact of the thigh with the edge of the tank and were not changed between successive measurements. Then, after water surface has calmed, the overflow valve was opened and the displaced water was collected for exactly 5 min. During this time subjects were requested to avoid any kind of movement. Volume was quantified by weighing the amount of displaced water (measurement error ±1.5 g approx.) with the assumption of 1 g corresponding to 1 ml of volume.

Impedance. Bioelectrical impedance measurements were conducted with a four electrode setup. Two electrodes (4 × 4 cm adhesive electrodes, Axion GmbH) were placed on the triceps surae muscle, one at the Achilles tendon distal of the muscle belly and the other at the proximal end of the medial caput of gastrocnemius muscle. Another pair of electrodes with an active area of 15 mm diameter (Covidien™, Kendall™ ECG electrodes H93SG, distance
between electrodes: 25 mm) was placed in direction of muscle fibres on the centre of the medial caput of gastrocnemius muscle belly (as recommended by SENIAM for the use in surface electromyography measurements, Hermens (1999)) in between the stimulation electrodes (see figure 2). A constant current square pulse (300 µA) with 1 ms duration and a repetition frequency of 13 Hz was applied for 20 s through the stimulation electrodes (Train/Delay Generator DG2A, square pulse; Constant Current Stimulator DS7A, Digitimer Ltd, England). Prior to electrode placement the skin was prepared with abrasive paste (Nupreb, Weaver and Company) to improve stimulation and measuring signal. Voltage was measured over a bandwidth of 4 to 650 Hz (PS11, THUMEDI GmbH & Co. KG, Germany, sampling rate 2048 Hz, high pass @ 4 Hz ± 3 dB4th order, low pass @ 650 Hz ± 3 dB11th order, passband ripple below 0.25 dB @ 20–500 Hz, noise below 0.6 µV rms, CMRR > 100 dB). Measurement uncertainty of the device is below 1% of the measured voltage. During measurement, participants were seated comfortably in an armchair in a relaxed position. The chair was adjusted to ensure a leg position of 120° knee angle and 90° ankle angle (see figure 3). Subjects were asked to relax and to avoid any movement during the measurement procedure to reduce noise and electrical signals by muscle activity.

Previously conducted test measurements showed 370–372 Hz to be the frequency band with least variation compared to nine other tested bands from 12 to 650 Hz and was therefore chosen for the present study.

Data was processed with custom-made software (THUMEDI GmbH & Co. KG, Thum, Germany). First, raw data was transformed from time to frequency domain using Fast Fourier Transformation (FFT) after applying a rectangular window with a size of 2048 samples—which results in a frequency resolution of 1 Hz. Finally, voltage was calculated for a specific frequency band (370–372 Hz) using root mean squares to determine lower leg impedance. Since the current as well as the shape of the pulses were constant, the measured frequency-specific voltages were only influenced by the impedance and are always in a strict linear relation to it. Thus, measured voltage can be used as an estimate to determine lower leg liquid distribution changes (oedema increase or decrease). Impedance was finally calculated by dividing the effective value of the voltage in the Range of 370–372 Hz by the effective value of the applied constant current. Considering the currents pulse shape, pulse duration, amplitude and repetition rate the effective current in the Range of 370–372 Hz is 0.465 µA (rms).
Muscle twitch force. MTF was measured by electrically stimulating the triceps surae muscle every 500 ms using a rectangular pulse of 1 ms duration and a constant current limited to 30 mA individually adjusted for each participant. The location of stimulation electrodes was first gauged by palpation and then by determination of the area corresponding to the maximum tolerable discomfort induced by stimulation yielding the maximum twitch force. Stimulation intensity was selected individually for each subject and remained constant for the three measurements. The resulting plantar flexion force (twitch force) was measured at the bottom of the forefoot using a custom-made device with a force transducer (strain gauge). Twitch forces were sampled at 1000 Hz and collected using custom software based on LabVIEW (National Instruments Corp., USA).

The means of three series of 30 twitches with a coefficient of variation under 3% after potentiation were used as MTF values (Garcia et al 2015). MTF measurement took about 3–4 min in total.

Subject positioning was the same as during BI measurement with the exception of fixating the leg with a strap to avoid upward movement generated by stimulation.

Procedure. All described measurements were recorded successively during three measurement periods by one of two different raters (R1 and R2). The measurements were repeated on a second experimental day (not more than 4 weeks apart from day one) by the other rater. Randomization ensured that 10 subjects were first investigated by R1 and consequently the other 10 subjects were first investigated by R2. Further, the subjects’ leg for WP was randomized (but was the same on both days), and then BI and MTF measurements were conducted on the other leg due to electrode placement.

Each experimental day started with the assessment of WP. After the first measurement the tank was refilled and the valve was opened to prepare for the second measurement. Meanwhile, subjects remained seated as pictured in figure 3. After attaching electrodes, testing signals and adjusting for sufficient stimulation intensity, BI and MTF were conducted consecutively. The next WP measurement followed approximately 30 min after WP 1. Directly after WP 2 and during tank preparation for WP 3, BI 2 and MTF 2 followed. Another 30 min after WP 2, the
third and last round of measurements was conducted. On a second day, the same subjects were assessed by the other rater at the same time of day (±1 h). R1 and R2 each tested ten people on day one and day two. Subject positioning, electrode placement and MTF intensity were carried out by R1 and R2 respectively.

Statistical analyses. Alpha level to determine statistical significance was set to 0.05. Results were analysed using JMP 11 (SAS Inc, Cary, NC, USA) and SPSS Version 21 (IBM SPSS Inc., Chicago, IL, USA). Heteroscedasticity and systematic bias were inspected visually using Bland–Altman plots, which include the differences of consecutive measurements plotted against their mean absolute values (Bland and Altman 1999). Furthermore, a dependent t-test was conducted to control for systematic bias (statistically significant differences) between M1 and M2 as well as M2 and M3 separately.

A one way analysis of variance (ANOVA) with the factor subject was calculated to describe within-subject standard deviation by residual mean square, which is also known as standard error of measurement (SEM) (Bland and Altman 1999). Some researchers describe this as ‘the most important type of reliability measure […] because it affects the precision of estimates of change in the variable of an experimental study’ (Hopkins 2000). The SEM value multiplied by 2.77 is called the repeatability coefficient, also known as smallest real difference (SRD), which describes the individual difference upon retesting and can therefore serve as a cut-off for change with 95% confidence. The inter-rater reliability was calculated using the intra-class correlation coefficient (ICC 2,1; two way random, single measures, Weir 2005) and the confidence intervals (CI), and by comparing SEM values. Datasets of R1 and R2 were tested for normal distribution using the Shapiro–Wilk-Test and additionally rated by histograms.

Results

Subjects

All subjects completed the entire procedure with both raters. All data from WP and MTF were available for data analysis. BI data showed some extreme values so that data from two subjects measured by R2 had to be excluded from data analysis. In another three subjects, BI data were not plausible for one of the three measurements. Table 1 shows the means (MN) and standard deviations (SD) of the three measurements by rater one and two for WP, MTF, and BI.

Waterplethysmography

WP results showed normal distribution for all data. Visual control of Bland–Altman plots showed homoscedastic distribution in each of the test–retest differences. Mean differences were statistically significant for both raters between M1 and M2 (R1 = 23 ml, p = 0.004; R2 = 19 ml, p = 0.027) but not significant between M2 and M3 (R1 = −6 ml, p = 0.45; R2 = 4 ml, p = 0.27) (see figures 4(a) and (b) for rater 1). SEM and SRD values for R1 were 27 and 75 ml, respectively, and for R2 23 and 64 ml, respectively. The inter-rater reliability for WP described by the ICC was 0.99 (CI: 0.98–0.99, p < 0.0001) (see table 2).

Bioelectrical impedance

Two datasets could not be analysed so that the number of subjects was reduced to 18. Shapiro–Wilk-Test also revealed normally distributed BI data for R1 and R2. Homoscedasticity and statistically significant differences between M1 and M2 (R1 = 3.9
Table 1. Mean (MN) and standard deviation (SD) for all three measurements of waterplethysmography (WP), impedance (BI) and muscle twitch force (MTF) measures for both raters (R1, R2).

<table>
<thead>
<tr>
<th>Measure Rater</th>
<th>WP in ml</th>
<th>BI in Ω</th>
<th>MTF in N</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>R1</td>
<td>R2</td>
<td>R1</td>
</tr>
<tr>
<td>M1</td>
<td>MN</td>
<td>SD</td>
<td>MN</td>
</tr>
<tr>
<td>R1</td>
<td>3077</td>
<td>321</td>
<td>3082</td>
</tr>
<tr>
<td>R2</td>
<td>3100</td>
<td>327</td>
<td>3101</td>
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<tr>
<td>M2</td>
<td>3094</td>
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<td>3077</td>
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<td>R1</td>
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<td>SD</td>
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<tr>
<td>R2</td>
<td>3100</td>
<td>327</td>
<td>3101</td>
</tr>
<tr>
<td>M3</td>
<td>3094</td>
<td>328</td>
<td>3105</td>
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</table>

Ω, p = 0.0001; R2 = 2.4 Ω, p = 0.049) and between M2 and M3 (R1 = 2.3 Ω, p = 0.012; R2 = 2.0 Ω, p = 0.008) occurred for BI data of both raters (see figures 4(c) and (d) for rater 1). SEM and SRD values for R1 were 3.8 and 10.5 Ω, respectively, and for R2 3.4 and 9.4 Ω, respectively. Intraclass correlation for R1 and R2 was 0.24 (CI: 0.07–0.51, p = 0.001) (see table 2).

Muscle twitch force

Normal distribution was given for datasets of both raters. MTF data also showed homoscedastic distribution of test–retest differences and statistically significant mean differences between M1 and M2 for rater 1 but not rater 2 (R1 = 0.13 N, p = 0.022; R2 = 0.12 N, p = 0.082) and no significant difference between M2 and M3 for both raters (R1 = 0.04 N, p = 0.37; R2 = 0.08 N, p = 0.12) (see figure 4(e) and (f) for rater 1). SEM and SRD values for R1 were 0.19 and 0.53 N, respectively. R2 had a SEM of 0.23 N and a SRD of 0.64 N. The inter-rater reliability for MTF was 0.71 (CI: 0.55–0.85, p < 0.0001) (see table 2).

Discussion

Swelling—lower leg volume

Waterplethysmography. Waterplethysmography has previously been used to determine lower leg oedema development while standing (Man et al 2003, Mosti and Partsch 2013). There are no standardised protocols in the literature recommending measurement procedure, basin volume/design or water draining time. Additionally, wide variations of water displacement based volumetry procedures are described in previous studies. Subject placement could either be sitting (Brijker et al 2000) or standing (Belczak et al 2009). Positioning of the foot and lower leg varied from touching the ground (Henschke et al 2006) to lifting the foot to a certain mark on the lower leg level to the surface of the water (Hartmann and Huch 2005). Another inconsistent measurement factor is the water draining time. Durations vary from 20 s using a special construction (Goldie et al 1974) to 2 and 5 min, respectively (Hartmann and Huch 2005, Belczak et al 2009) or until water was drained completely (Henschke et al 2006). In most cases waterplethysmography measurements only included the distal lower leg up to a few centimetres above ankle level depending on the design of water tanks (Petersen et al 1999, Henschke et al 2006, Mosti and Partsch 2013). In order to measure oedema of a large part of the lower leg in the present study the authors chose to use a water tank with 50 cm height in contrast to previous studies using devices only covering the distal lower leg up to a few centimetres above ankle level (Petersen et al 1999, Henschke et al 2006, Mosti and Partsch 2013).
Figure 4. (a)–(f) Bland–Altman plots of waterplethysmography (a) and (b), impedance (c) and (d) and muscle twitch force (e) and (f) measurements showing differences and mean values in volume, voltage and twitch force of each subject measured by rater 1.
Water temperature of 25–30°C was chosen consistent with previous studies (Rabe et al. 2010). Additionally, limiting water draining time to 5 min allows measurements in the course of standing work without excessively interfering with the work process. Evaluating the planned investigation and previously conducted test measurements, the authors chose the procedure and setting described above.

Our results showed a standard error of measurement of 23 and 27 ml corresponding to a 0.7 and 0.9% error, respectively (see table for mean values of the measurements). Rabe et al. (2010) report in their review about lower leg WP that measurement error was described as being between 0.1 and 1.0%. Additionally, the authors conclude that measurement error should not be above 20 ml because that would not allow for detecting the effects of antidiuretic drugs, which can decrease lower leg volume by ca. 30 ml (Rabe et al. 2010). However, average lower leg volume increases are expected to be greater than 100 ml or 3–5% after prolonged standing as has been shown in several previous studies (Hansen et al. 1998, Belczak et al. 2009).

Measured systematic error shown in Bland–Altman plots can be explained by an actual increase in lower leg volume from M1 to M2. One possible explanation could be that between M1 and M2, the subject’s leg (of which volume was measured) was in a sloped position (as seen in figure) allowing an increase of lower leg’s volume, which is known to occur during sitting (Chester et al. 2002, Herold 2015). In addition, WP was performed immediately after arriving, getting the procedure explained and signing informed consent (only on day one). Another possibility is that this may have led to an underestimation of LLV due to the preceding activation of the muscular venous pump (by walking or biking). Solving these issues by standardising leg position in between measurements and including a seated resting period before M1 could have further improved reliability of WP.

Inter-rater reliability can be regarded as very good taking into account the ICC, which showed a nearly perfect agreement, and SEM values, which were only 4 ml apart. Bioelectrical impedance. For the present study we used a measuring frequency of 370–372 Hz to mainly record extracellular fluid shifts (Kanai et al. 1983). We assume that focusing on extracellular fluid is important since it is related to the pathophysiology of venous diseases. Lower leg volume increases directly after a posture shift from sitting/lying to standing due to an immediate gravitational fluid redistribution (Stick et al. 1985). After a few minutes, orthostatic pressure induces an increase of extracellular fluid into capillaries and the lymphatic system. If lower leg muscle activity is insufficient (muscular venous pump), like it is the case in prolonged standing, venous pressure increases and leads to further stretching of vessels. This process can lead to sacculation (varicose veins) and venous insufficiency in the long term (Ganasegeran et al. 2014, Herold 2015).

Test–retest reliability was found to be very good in previous studies both in healthy (Mally et al. 2011) and lymphatic subjects (Czerniee et al. 2009, Jain et al. 2010) as well as

<table>
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<th>Measure</th>
<th>WP (ml)</th>
<th>BI (Ω)</th>
<th>MTF (N)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>R1</td>
<td>R2</td>
<td>R1</td>
</tr>
<tr>
<td>SEM</td>
<td>23</td>
<td>27</td>
<td>3.8</td>
</tr>
<tr>
<td>SRD</td>
<td>64</td>
<td>75</td>
<td>10.5</td>
</tr>
<tr>
<td>ICC</td>
<td>0.98 (p &lt; 0.0001)</td>
<td>0.24 (p = 0.001)</td>
<td>0.71 (p &lt; 0.0001)</td>
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lower legs (Pichonnaz et al. 2015) and forearms (Czerniec et al. 2009, Jain et al. 2010) using commercial BI devices. Although no comparable investigation could be found using the exact same measuring frequencies or same general setup. The SEMs of 1.75 (R1) and 1.59 \(\mu V\) (R2) correspond to approximately 5% of the measured BI values (see table 1). In previous studies, effects of prolonged standing on BI change of over 20% compared to baseline have been shown (Stick et al. 1992, Sanders et al. 2012). Therefore, the authors conclude that sufficient test–retest reliability is given for the conducted procedure. The same problem regarding systematic error as described for WP was found for BI from M1 to M2 and M2 to M3 as seen in Bland–Altman plots indicating a volume decrease from M1 up to M3 for both raters. This finding is in contrast to the results from the leg on which WP was conducted. The reason for that could be a fourth measurement procedure not described in the present publication. It was an explorative approach to investigate reliability of a force sense measurement procedure for which the leg had to be lifted in a mechanical device to about head level (while sitting) and at the same time actively contracting calf muscles. This could have led to an activation of the muscle venous pump and further to a lower leg volume decrease and thus to measured statistical difference. As mentioned in the WP discussion section, a standardised lower leg positioning in between measurements may improve SEM values further so that an underestimation of reliability is probable in this case.

Inter-rater reliability as calculated by ICC (2,1) was very low at 0.24. However, SEM values only differed minimally. This could be because R1 and R2 often measured very different absolute values comparing individual subjects. For example values recorded by R1 for subject 20 were 23.29, 27.73 and 29.63 \(\mu V\) and by R2 on a different day 42.29, 43.72 and 47.96 \(\mu V\). The reason for these differences most probably is the electrode placement, which R1 and R2 conducted separately and can lead to a difference of inter-electrode distance of a few centimetres and further to different BI results. Therefore, ICC calculation may not be appropriate for BI measurement and, therefore, inter-rater reliability evaluation should be carried out by comparing SEM values alone.

Although water displacement is still regarded as the gold standard in measuring volume changes (Petersen et al. 1999, Henschke et al. 2006), plenty of other methods with specific pros and cons were used previously. Comparatively simple methods, requiring low costs, are circumference measurements that can lack precision if not conducted properly and often overestimate total volume depending on used model (Sander et al. 2002, Taylor et al. 2006). Other techniques like perometry, dual energy x-ray absorptiometry (DXA), BI or air plethysmography can also produce valid and reliable data measuring both healthy persons and patients with lymphedema. These methods require expensive devices and in the case of air plethysmography, cannot be used segmentally (Wagner and Heyward 1999, Delombe et al. 2007, Ridner et al. 2007, Gjorup et al. 2010, Newman et al. 2013). The biggest advantage of BI measurements is the comparably low required measuring time (in our case 20s). For measuring lower leg oedema development in standing work, we wanted to include both the gold standard in volumetry and another less time consuming method and therefore chose waterplethysmography and bioelectrical impedance.

Muscle twitch force

There are no studies available investigating reliability of MTF known to the authors. However, MTF has previously been conducted in the triceps surae muscle during multiple hours of standing. Garcia et al. (2015) found a force reduction after electrical stimulation compared to baseline of 30–40% after standing for more than 4h. Calculated SEM values of 0.19N for R1 and
0.23 N for R2 corresponding to about 11 and 13%, respectively, represent test-retest reliability and can, therefore, be described as sufficient for detecting measured effects after multiple hours of standing.

Measured statistically significant differences (systematic error) could indicate an influence of inter-cellular liquid distribution, changing the lower leg impedance (as described in previous section) due to measuring procedure and MTF. Further investigation to clarify such connection is needed. Additional SEM improvement may be achieved by methodological adaptation of the measuring procedure described for WP and BI.

Inter-rater reliability as calculated by an ICC of 0.71 is found to be moderate. However, in this case the problem is similar to the one described for BI data. Both raters conducted electrode placement separately leading to different absolute values for individual subjects. Furthermore, homogenous data with low values and low standard deviations will likely result in lower ICCs (Atkinson and Nevill 1998), which may be the case for present results. Comparing the SEMs of R1 and R2 (0.19 and 0.24) differences can be considered to be very low and therefore inter-rater reliability described as good.

Conclusions

All measurements conducted in present study showed satisfying test–retest- and inter-rater reliability for standing work evaluation of lower leg oedema (WP and BI) and muscle fatigue (MTF). Inter-rater reliability evaluated by calculating ICC has to be interpreted cautiously. The results of present investigation will be very helpful for interpretation of results measured during multiple hours of standing.

Acknowledgments

The work of the Institute of Occupational and Social Medicine and Health Services Research is supported by an unrestricted grant of the employers’ association of the metal and electric industry Baden-Württemberg (Suedwestmetall).

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