Exercise induced dehydration status and skinfold compressibility in athletes: an intervention study

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Background and Objectives: Skinfold thickness assessment is a widely recognized technique for the estimation of body adiposity and fat free mass. This method assumes that skinfolds’ compressibility is constant but there are some factors that could influence its compressibility. This study aims to evaluate whether the skinfolds’ compressibility is influenced by hydration status. Methods and Study Design: An intervention study was conducted in a sample of 22 adult male amateur soccer players, who took part in a 90min simulated soccer match. Before and after the intervention skinfolds thicknesses were measured in eight anatomical sites. An electronic caliper, Lipotool, was used to collect and record 120 values during 2s of evaluation. To analyze skinfolds’ compressibility, two methods were used: identification of lowest skinfold thickness measurement (SL) and SH = 110% x SL, and the parameter TAU (τ) determination. Baseline hydration status was evaluated by total body water (TBW) through multifrequency bioimpedance analysis. Dehydration was assessed by the difference of body weight before and after the intervention. Results: The intervention resulted in a loss of 2.11% of participants’ baseline weight. The skinfolds thicknesses, assessed by SL and SH, were significantly higher after exercise for all skinfolds except for skinfolds at iliac crest and abdominal. This intervention did not affect skinfolds’ compressibility when assessed by τ. However, an association between dehydration and medial-calf skinfold compressibility was found (r=0.48, p=0.042). Conclusions: Although an increase in the skinfolds thickness after the intervention was found, skinfolds’ compressibility did not change.

Key Words: skinfold’ thickness, dehydration, anthropometry, compressibility, Lipotool

INTRODUCTION

The use of anthropometric measurements to assess body composition has been widely recognized.1 The skinfold thickness assessment is a simple and a non-invasive technique for the estimation of body adiposity and fat free mass.2,3 The thickness of a compressed double layer of skin and subcutaneous adipose tissue is measured with a caliper whose jaws exert a constant pressure of 10g/mm². The skinfold should be representative of the uncompressed single layer of adipose tissue, indicating total subcutaneous adiposity, from which body adiposity can be predicted.4,6

The existence of two types of compressibility has been consistently demonstrated: the dynamic which refers to the decrease in skinfolds thickness after the first application of the caliper, and the static, which corresponds to the variability of skinfolds’ compressibility in different body sites.5,7,8 Furthermore, studies comparing skinfolds thickness measurements with radiographic methods, cadaver studies and ultrasound images have suggested that factors such as sex, age, skin tension, distribution of fibrous tissue and blood vessels, and nutritional status, including hydration, may influence the skinfolds’ compressibility.4,6,8 These dissimilarities in tissues compressibility may affect differentially the skinfold caliper reading at a particular anatomical site and the corresponding adipose thickness. This might induce error in the estimation of the skinfold thicknesses and consequently in body fatness estimates based on these values.9

Lipotool11 is a wireless digital skinfold caliper that applies a constant pressure of 10 mol/mm² and records sixty skinfolds thickness measurements per second. This constant recording during the 2s of measurement will firstly enable the documentation of the skinfolds’ compressibility.12

Hydration status is a determinant of the compressibility.4,6,8 It is well known that water is a component of connective tissue; adipose tissue has 20% of water in its

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composition. Thus, the proportion of intra and extra cellular water affects the thickness of the skinfolds and consequently its compressibility. Therefore, the aim of this study was to evaluate to which extent the hydration status influences the skinfolds’ compressibility.

METHODS

Ethics committee

The study protocol was approved by the Ethics Committee of the Faculty of Sport from the University of Porto (number CEFADE 30.2014). All participants gave their oral informed consent.

Participants/design

An intervention study was conducted involving a convenience selected sample of 22 adult male amateur soccer players – two teams. Subjects’ characteristics are displayed in Table 1. This intervention consisted of a simulated match of 90 min with a 15 min break in a warm outdoor environment (circa 22°C). All measurements were performed before and after the match. Fluid intake was not allowed during the match and between measurements.

The study was designed and conducted in accordance to the Helsinki Declaration.

Data collection

Skinfold thickness at eight sites (triceps, biceps, subscapular, iliac crest, abdominal, supraspinale, front-thigh, and medial-calf) were measured using ISAK protocol by a ISAK level two anthropometrist. Skinfolds were measured using a wireless digital skinfold caliper, the Lipotool which applies a constant pressure of 10 mmHg and enable to record sixty measurements per second, for 2 s, allowing the register of the dynamic compressibility of the skinfolds thickness. The Lipotool automated digital device has proven accuracy in the evaluation of skinfolds thickness, with a resolution of 0.1 mm.

Participants’ hydration status before the match was evaluated through total body water (TBW) estimation from bioelectrical impedance analyses (BIA), with a Tanita Body Corporation Multi Frequency Analyzer, model MC-180MA® (Tanita Corporation, Tokyo, Japan). Weight loss during the intervention was used as a surrogate marker of dehydration, through the difference of the subject’s body weight before and after the match. Body weight was also measured using the above mentioned Tanita scale to the nearest 0.01 kg and height was assessed using a stadiometer (Seca 708; Seca limited, Birmingham, UK), with a resolution of 0.001 m, according to ISAK protocol.

Data analysis

Two methods were used in order to analyze the skinfolds’ compressibility. In a first approach, from the 120 measurements two distinct points (L and H) were identified for each skinfold. The point L (S_L, in mm) corresponds to the lowest skinfold thickness measure and the time when L was obtained for the first time was defined as T_L. The point H corresponds to 110% of the skinfold thickness of point L (S_H = 110% x S_L) and the first time when H was gathered was defined as T_H.

In the second approach, the behaviour of the exponential graphic representation of each skinfold measurement was characterized. TAU (τ), a physical parameter which is a characteristic of dynamic systems, like the human body, was identified to illustrate the skinfolds’ compressibility. TAU corresponds to the time it takes the curve to decrease 1/e ≈ 36.8%, e being the function exponent.

In order to evaluate the relationship between hydration status and skinfolds’ compressibility, four variables were created as follows: the percentage of weight lost during the intervention and the differences between T, SL and SH before and after the intervention.

Measurements for iliac crest, abdominal, supraspinale, front-thigh, and medial-calf skinfolds were not obtained for one participant and for these skinfolds results are presented for 21 subjects.

Statistical analysis

Values are expressed as mean and standard deviations (SD). Normality of variables distribution was assessed with Shapiro-Wilk test. Differences amongst variables with normal distribution were assessed using Student t-test for paired samples with a confidence interval of 95%. The Wilcoxon test was used for variables with non-normal distribution. Bland and Altman plot analysis was performed to evaluate the agreement between SL before and after the intervention. Pearson correlation was carried out for variables with normal distribution while Spearman correlation was used for variables with non-normal distribution. The MATLAB® software (The MathWorks, Inc., Natick, Massachusetts, USA), was used to calculate τ.

Further analyses were conducted considering the sample stratified by the median value of the distribution of each skinfold thickness values collected before the game. From this stratification two groups were created, one with thinner skinfolds (below the median value) and another one with thicker skinfolds, corresponding to skinfolds values equal or higher than the median value.

A statistical significance level of 0.05 was used and analyses were carried out using the Software Package for Social Science® (SPSS), version 23.0 for Windows® 8.1.

RESULTS

The mean age of the sample is 24.7 years, ranging between 21 and 34 years and body mass index [weight(kg)/height²(m)] Mean (SD) is 23.75 (2.25), Mean (SD) TBW before the intervention was 46.8 (5.33) kg, with 30.2 (4.17) kg in the intracellular space and 16.6 (1.25) kg in the extracellular space. The mean percentage of body weight lost during the intervention was 2.11% (SD=0.58%), corresponding to a statistically significant difference between the body weight before and after the intervention (p<0.001).

When skinfolds thickness, S_L, obtained before and after the intervention were compared, statistically significant differences were found for all skinfolds except for iliac crest and abdominal (Table 1). Although no statistically significant differences were noted for these two skinfolds thickness comparisons, both presented the same trend as the others. As an example of the behavior of the same skinfold before and after intervention, Figure 1 shows the evolution of medial-calf skinfold, on the same player,
Dehydration and skinfold compressibility

before and after intervention.

When stratified analyses according to skinfold thickness were carried out similar results were obtained. However, for triceps, biceps and front-thigh skinfolds, significant differences were found only for the group with thinner skinfolds. Nevertheless, no statistical differences were identified for Tt and Th values obtained before and after the intervention, considering the total sample and also the stratified analysis.

Bland and Altman plot for the agreement between Sl before and after the intervention shows that the mean differences are all negative, close to zero and that individual differences tend to be superior for higher mean values of skinfolds thicknesses (Figure 2).

When the skinfolds’ compressibility was assessed through τ, no statistically significant differences were identified when total sample was analyzed. However, a trend to higher compressibility after the intervention was found for all skinfolds excluding biceps and front-thigh, presented higher compressibility (lower τ values) after the intervention. However, for the subjects with thinner skinfolds, statistically significant differences were identified for front-thigh and medial-calf skinfolds, the former showing lower compressibility and the latter higher compressibility after the intervention.

Regarding the association between dehydration and skinfolds’ compressibility assessed by the difference of τ before and after the intervention, a significant correlation was found only for the medial-calf skinfold (Table 3). No significant associations were identified when the correlation between dehydration percentage and the differences of Sl and Sh before and after the intervention were analysed.

DISCUSSION

According to our knowledge, this is the first study that has documented the influence of a physical exercise intervention in skinfolds thickness and compressibility.

The differences concerning the time at which Sl and Sh were obtained before and after the game were not significant. However, the intervention resulted in a thickness increase for all skinfolds (through Sl and Sh analyses), with statistical significance for triceps, biceps, subscapular, supraspinale, front-thigh and medial-calf. These results are in line with those previously described by Consolazio et al in 1963.22 Using skinfolds repeated measurements in different days, they concluded that skinfolds assessments should not be carried out after training or competition, because exercise and heat produce hyperaemia, an increased blood flow in the skin, with a concomitant increase in the skinfold thickness.22

Present findings add further evidence supporting that the assessment of skinfolds’ thickness should be made before exercise. If skinfolds measurements are carried out after exercise, the adiposity estimated from these values could be biased towards overestimation.

Despite the increase of the skinfolds thickness after the intervention, these changes are very small in absolute terms, explaining the lack of statistical significance found regarding the time at which Sl and Sh were obtained.

When skinfolds’ compressibility was assessed by τ no statistically significant differences were found when total sample was analyzed. However, a trend to higher compressibility after the intervention was found for all skinfolds excluding biceps and front-thigh.
Table 1. Skinfolds sites and skinfolds thickness before and after intervention (n=22)

<table>
<thead>
<tr>
<th>Skinfolds</th>
<th>Shl before (mm)</th>
<th>Shl after (mm)</th>
<th>p</th>
<th>Shl before (mm)</th>
<th>Shl after (mm)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triceps</td>
<td>12.1 (5.3)</td>
<td>13.0 (5.5)</td>
<td>0.012</td>
<td>11.0 (4.9)</td>
<td>11.8 (5.0)</td>
<td>0.017</td>
</tr>
<tr>
<td>Biceps</td>
<td>5.7 (2.1)</td>
<td>6.0 (2.1)</td>
<td>0.028</td>
<td>5.2 (1.9)</td>
<td>5.4 (1.9)</td>
<td>0.028</td>
</tr>
<tr>
<td>Subscapular</td>
<td>13.8 (5.6)</td>
<td>14.9 (6.3)</td>
<td>&lt;0.001</td>
<td>12.5 (5.1)</td>
<td>13.5 (5.7)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Iliac Crest</td>
<td>13.8 (7.4)</td>
<td>14.3 (7.8)</td>
<td>0.180</td>
<td>12.6 (6.8)</td>
<td>13.0 (7.1)</td>
<td>0.191</td>
</tr>
<tr>
<td>Abdominal</td>
<td>18.6 (10.1)</td>
<td>19.3 (11.3)</td>
<td>0.149</td>
<td>16.9 (9.2)</td>
<td>17.5 (10.3)</td>
<td>0.144</td>
</tr>
<tr>
<td>Supraspinale</td>
<td>13.6 (7.1)</td>
<td>15.3 (8.5)</td>
<td>0.001</td>
<td>12.4 (6.5)</td>
<td>13.9 (7.7)</td>
<td>0.001</td>
</tr>
<tr>
<td>Front-thigh</td>
<td>16.2 (7.0)</td>
<td>17.4 (6.8)</td>
<td>0.008</td>
<td>14.7 (6.3)</td>
<td>15.8 (6.2)</td>
<td>0.008</td>
</tr>
<tr>
<td>Medial-calf</td>
<td>9.7 (4.4)</td>
<td>10.4 (4.8)</td>
<td>&lt;0.001</td>
<td>8.8 (4.0)</td>
<td>9.5 (4.3)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

*Values are expressed as mean (SD); SH=110% of point L; SL=Lowest of the 120 measurements.
†p<0.05 was considered significant; Wilcoxon test except for triceps, biceps and front-thigh for which Student t-test for paired samples was used.

Table 2. Skinfolds sites and corresponding τ (s) before and after the intervention for total sample and stratified by skinfolds thickness (n=22)

<table>
<thead>
<tr>
<th>Skinfolds†</th>
<th>T_before</th>
<th>T_after</th>
<th>p</th>
<th>T_before</th>
<th>T_after</th>
<th>p</th>
<th>T_before</th>
<th>T_after</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total sample</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Triceps</td>
<td>0.36 (0.12)</td>
<td>0.34 (0.16)</td>
<td>0.475</td>
<td>0.32 (0.11)</td>
<td>0.32 (0.16)</td>
<td>0.983</td>
<td>0.41 (0.12)</td>
<td>0.35 (0.16)</td>
<td>0.361</td>
</tr>
<tr>
<td>Biceps</td>
<td>0.36 (0.18)</td>
<td>0.36 (0.15)</td>
<td>0.638</td>
<td>0.40 (0.22)</td>
<td>0.31 (0.16)</td>
<td>0.279</td>
<td>0.33 (0.13)</td>
<td>0.40 (0.13)</td>
<td>0.104</td>
</tr>
<tr>
<td>Subscapular</td>
<td>0.45 (0.15)</td>
<td>0.43 (0.22)</td>
<td>0.734</td>
<td>0.47 (0.17)</td>
<td>0.40 (0.26)</td>
<td>0.468</td>
<td>0.43 (0.14)</td>
<td>0.46 (0.18)</td>
<td>0.636</td>
</tr>
<tr>
<td>Iliac Crest</td>
<td>0.40 (0.15)</td>
<td>0.38 (0.15)</td>
<td>0.638</td>
<td>0.42 (0.08)</td>
<td>0.45 (0.06)</td>
<td>0.451</td>
<td>0.42 (0.16)</td>
<td>0.32 (0.18)</td>
<td>0.214</td>
</tr>
<tr>
<td>Abdominal</td>
<td>0.47 (0.16)</td>
<td>0.44 (0.16)</td>
<td>0.566</td>
<td>0.45 (0.14)</td>
<td>0.53 (0.07)</td>
<td>0.086</td>
<td>0.48 (0.18)</td>
<td>0.36 (0.16)</td>
<td>0.075</td>
</tr>
<tr>
<td>Supraspinale</td>
<td>0.46 (0.15)</td>
<td>0.45 (0.14)</td>
<td>0.903</td>
<td>0.41 (0.18)</td>
<td>0.47 (0.15)</td>
<td>0.260</td>
<td>0.50 (0.11)</td>
<td>0.44 (0.14)</td>
<td>0.328</td>
</tr>
<tr>
<td>Front-thigh</td>
<td>0.43 (0.13)</td>
<td>0.46 (0.10)</td>
<td>0.394</td>
<td>0.38 (0.09)</td>
<td>0.50 (0.03)</td>
<td>0.011</td>
<td>0.47 (0.15)</td>
<td>0.41 (0.12)</td>
<td>0.213</td>
</tr>
<tr>
<td>Medial-calf</td>
<td>0.47 (0.28)</td>
<td>0.32 (0.14)</td>
<td>0.063</td>
<td>0.59 (0.35)</td>
<td>0.29 (0.09)</td>
<td>0.008</td>
<td>0.36 (0.16)</td>
<td>0.35 (0.17)</td>
<td>0.722</td>
</tr>
</tbody>
</table>

*Values are expressed as mean (SD).
†p<0.05 was considered significant; Wilcoxon test for variables with non-normal distribution and Student t-test for paired samples for variables with normal distribution.

Table 3. Correlation between changes in body mass and τ, SL and SH differences before and after the intervention

<table>
<thead>
<tr>
<th></th>
<th>T</th>
<th></th>
<th></th>
<th>S_h</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)†</td>
<td>r</td>
<td>p</td>
<td>Mean (SD)†</td>
<td>r</td>
<td>p</td>
</tr>
<tr>
<td>Triceps</td>
<td>0.28 (0.18)</td>
<td>0.58</td>
<td>0.797</td>
<td>-0.83 (1.51)</td>
<td>-0.05</td>
<td>0.837</td>
</tr>
<tr>
<td>Biceps</td>
<td>0.01 (0.22)</td>
<td>0.16</td>
<td>0.467</td>
<td>-0.26 (0.51)</td>
<td>-0.15</td>
<td>0.509</td>
</tr>
<tr>
<td>Subscapular</td>
<td>0.19 (0.26)</td>
<td>0.18</td>
<td>0.421</td>
<td>-0.98 (1.60)</td>
<td>-0.12</td>
<td>0.591</td>
</tr>
<tr>
<td>Iliac Crest</td>
<td>0.02 (0.21)</td>
<td>-0.03</td>
<td>0.931</td>
<td>-0.43 (1.41)</td>
<td>0.08</td>
<td>0.748</td>
</tr>
<tr>
<td>Abdominal</td>
<td>0.02 (0.25)</td>
<td>0.20</td>
<td>0.377</td>
<td>-0.67 (2.19)</td>
<td>0.07</td>
<td>0.763</td>
</tr>
<tr>
<td>Supraspinale</td>
<td>0.00 (0.22)</td>
<td>-0.21</td>
<td>0.370</td>
<td>-1.55 (1.81)</td>
<td>0.04</td>
<td>0.874</td>
</tr>
<tr>
<td>Front-thigh</td>
<td>-0.03 (0.17)</td>
<td>-0.33</td>
<td>0.140</td>
<td>-1.07 (1.66)</td>
<td>0.23</td>
<td>0.306</td>
</tr>
<tr>
<td>Medial-calf</td>
<td>0.15 (0.33)</td>
<td>0.48</td>
<td>0.042†</td>
<td>-0.67 (0.65)</td>
<td>0.08</td>
<td>0.725</td>
</tr>
</tbody>
</table>

*Values of T, S_h and S_h differences are expressed as mean (SD); Pearson correlation for variables with normal distribution and Spearman correlation for variables with non-normal distribution; r – correlation coefficient value.
†p<0.05 was considered significant.
folds, except for biceps and front-thigh. Considering the occurrence of significant dehydration during the intervention \(p<0.001\), these results are in line with the theoretical model proposed by Hattori K et al that show higher compressibility associated with lower levels of adipose tissue hydration.\(^8\) On the contrary, a previous exploratory study that used \(\tau\) to explore skinfold compressibility in a free living individuals’ sample, showed that subjects with lower body water estimated by BIA analysis exhibits a lower compressibility.\(^9\) These discrepancies could be explained by the different analysed samples.

Total body water is defined as the fluid that occupies intracellular and extracellular spaces and represents approximatley 63.3\% (0.6 L/kg) of body mass.\(^2\) Total body water approximates “euhydration” when morning body weight is near to the normal baseline, fluid intake is adequate, urine color is pale yellow and volume is normal.\(^2\) As these parameters were not assessed in present study, the “euhydration” status of the athletes at the beginning of the game cannot be confirmed. However, the mean TBW before the intervention was 46.8 kg, 30.2 kg in the intracellular space and 16.6 kg in the extracellular space showing that these parameters are in line with the literature, that describes a TBW of 42 L for an individual weighing 70 kg.\(^{20,23}\) When the results are analyzed for each subject individually, only four participants presented lower values than this cut off.

Body mass changes cannot be regarded as the “golden standard” for the assessment of hydration status fluctuations and there are more valid and accurate techniques, such as plasma osmolality. However, the American College of Sports Medicine considers this technique not practical, especially for use in field studies.\(^20\) In contrast, body weight measurement is a simple and effective tool to assess fluid balance with proven sensitivity for the estimation of acute TBW changes.\(^20,23-25\)

A mean body weight loss of 2.11\% occurred during the intervention. This result is higher than previously found by Arnaoutis G et al that showed a mean body weight loss during 90min of training of -1.1\%\(\pm\)0.07\%.\(^26\) These disparities could be explained by the fact that the present study protocol advocated a total fluid restriction during the intervention, while in Arnaoutis study the athletes consumed fluids ad libitum throughout their game. Present results also confirm the result of the intervention on body mass reduction.

In relation to the influence of the hydration status in the skinfolds’ compressibility, a significant correlation was found only for the medial-calf skinfold, when assessed through \(\tau\) difference before and after the intervention. Although the correlation between hydration and skinfolds’ compressibility has been proposed previously,\(^9\) to the best of our knowledge, no previous work has studied this effect.

On the other hand, despite the suggestion that dehydration may cause an increase in the skinfolds thickness due to changes in skin turgidity or tenseness,\(^22\) no significant correlation was found between the hydration status and the skinfolds thickness. This is in line with the results obtained by Norton K et al that did not find differences between skinfolds taken before and after moderate dehydration induced by heat and/or exercise.\(^57\)

However, it should be noted that the absence of significant comparisons can be result of type II errors, related to the study low sample size and also by the fact that the differences in the skinfolds thickness and hydration status before and after the intervention are very small. Therefore, the results of this exploratory study cannot be generalized to samples with other characteristics. Another limitation of present study is the difficulty to confirm the athletes’ “euhydration” status before the game, as BIA is not the reference method to assess TBW.\(^3\)

On the other hand, the main strength of this study is related to the possibility of measuring, monitoring and comparing the effect of an intervention in the skinfolds compressibility for the first time, as the new skinfold caliper used for skinfolds measurements allows 120 values within 2 s of measurement.

Future research will be crucial, especially using larger samples and samples with different characteristics, to confirm our preliminary results regarding the influence of the hydration status on the skinfolds thickness and compressibility and to fill gaps of the present study.

**AUTHOR DISCLOSURES**

The authors declare no conflict of interest.

**REFERENCES**