Comparison of 24-Hour Whole Body Versus Patch Tests for Estimating Body Surface Electrolyte Losses

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Purpose: To compare dermal electrolyte loss between whole body and regional patch methods in women during 24-h. Methods: Dermal loss was collected in 6 healthy women mean age 27 ± 4 years, while consuming 936 mg/d sodium, 1764 mg/d potassium, 696 mg/d calcium, and 152 mg/d magnesium. Twenty-four hour whole body dermal loss was collected using cotton suits by a washdown procedure. Twenty-four hour patch loss was collected from 8 patches placed on the legs, arms, and back. Results: Dermal loss from whole body was 108 ± 110 mg/d sodium, 133 ± 87 mg/d potassium, 103 ± 22 mg/d calcium, and 35 ± 13 mg/d magnesium. Electrolyte content from the 8 patches was similar among sites and ranged from 1.01–1.41 mg/d sodium, 0.35–0.83 mg/d potassium, 1.0–1.45 mg/d calcium, and 0.43–0.49 mg/d magnesium. Projections from patches to whole body by the ratio of body surface area appear to overestimate actual whole body losses by 3.2X for sodium and calcium, 3.6X for magnesium, and 1.3X for potassium. Conclusions: Regional patch methods are more appropriate for relative comparisons than for accurately determining total daily dermal electrolyte losses.

Key Words: dermal loss, electrolytes, women, patches

Introduction

The determination of sweat electrolyte loss is necessary for the estimation of daily electrolyte requirements. For this purpose, different methods to collect sweat and other surface losses from the whole body and from localized regions of the body have been developed. Sweat electrolyte secretion and concentration have been measured utilizing special suits for whole body during short periods of time (1–3), and for 24-h (4–8) in men. Others have measured sweat from arm bags (3, 9), and patches for short period of time on the arms (10, 11), legs (10), chest (6), or back (6, 12), and patches for long periods of time on the back and abdomen (13). Since these studies reported sweat under different conditions (exercising or heat stress), periods of time, and methods (patches, bags, suits), there are widely varying results, which are not comparable. Therefore, it is difficult to accurately establish true human sweat electrolyte secretions and losses in 24-h, especially for the whole body during normal conditions.
Furthermore, studies have compared sweat electrolyte loss from regional methods with whole body procedures (3, 6, 7, 12), but only in men and for a short period of time. Most studies measure sweat loss in a small area of the body and then project to whole body. This procedure may not be accurate, since many of these methods enclose the skin with a bag or a patch, which raises the local skin temperature or humidity, leading to higher electrolyte sweat concentration and different sweat composition (6, 12).

No study to date has compared dermal electrolyte loss from a regional versus whole-body procedure in women under normal conditions during 24-h. Therefore, the objectives of the present paper are: to compare dermal electrolyte loss in 24-h from a regional patch method to a whole body washdown procedure, to determine the accuracy of projecting from the regional method to the whole body washdown procedure, and to compare dermal electrolyte loss from patches placed at different sites of the body in young adult females.

Methods

Subjects and Experimental Design

Six healthy women volunteered from Purdue University campus in West Lafayette, Indiana in 1999 to participate in a controlled diet, free-living study for 3 days. This study was done during the months of May and June, with a mean temperature of $20 \pm 7.8$ °C and mean humidity of $73.5 \pm 28.7\%$. Subjects were aged 22–29 years old. Subjects’ height and mass were measured with a Health-O-Meter Scale (Bridgeview, IL, USA). On the second day of the study, subjects were instructed to collect 24-h whole-body surface losses, and on the third day, the 24-h patch losses.

Subjects were studied under controlled diets to decrease the variability of dermal electrolyte loss between the 2 days the tests were performed. A duplicate composite of the day’s meal was stored for future analysis of electrolytes. The diet contained 936 mg/d sodium, 1764 mg/d potassium, 696 mg/d calcium, and 152 mg/d magnesium. Furthermore, the two tests were performed on consecutive days during the same stage of the menstrual cycle for each individual, to decrease variability due to the cyclic fluctuations, since progesterone surge induces an increase in sweat sodium loss in the pre-ovulatory stage (14).

Daily physical activity level was measured by the Framingham Physical Activity Index during the 2 testing days (15). This index has been previously validated (16, 17) and divides the daily activity as sleep, sedentary, slight, moderate, or heavy activity. Subjects filled out a questionnaire with the number of hours spent on each activity level, and then it was multiplied by a factor derived from the estimated oxygen consumption requirement from each level (1 for sleep, 1.1 for sedentary, 1.5 for slight, 2.4 for moderate, and 5 for heavy activity). Subjects were asked to maintain their exact same level of physical activity between the 2 testing days.

24-Hour Whole-Body Dermal Electrolyte Loss Collection

Dermal loss was collected during 24-h while subjects wore 100% cotton long sleeve shirt and long pants and 100% cotton underwear and socks (Lands End, UK). This suit and all the towels, washcloths, and pillowcases used for the study were previously
chemically treated. The materials were first soaked in free electrolyte detergent (Alconox, NY, USA) and de-ionized (DI) water for 12-h. Then they were rinsed two times with DI water and then acid washed in 0.1-N acetic acid solution for 24-h. Two 10-ml aliquots were collected from the acid wash for analysis. The materials were rinsed again with DI water two times and another 2 × 10-ml tubes were collected from the last rinse for blanks. No electrolytes were detected from either the acid rinsing or the blanks. The materials were dried and stored in plastic bags until ready to be used. All the plastic materials used were also pre-acid washed, and no electrolytes were detected.

Prior to wearing this suit, subjects showered normally. Next, subjects rinsed themselves thoroughly with approximately 950 ml of 0.003% polyoxethylene 23-lauryl ether detergent (Brij 35, Sigma, MO, USA) using a chemically treated washcloth followed by 950 ml of DI water only. Subjects then stepped inside a large electrolyte-free plastic bag and rinsed again thoroughly with 950 ml of DI water inside the bag. Subjects dried with a chemically treated towel and dressed with the chemically treated clothing for 24-h. Breathable paper outer garments and shoes (Fisher, PA, USA) were worn to protect the clothing from contamination. Two 10-ml aliquots were collected from the rinse left in the bag and analyzed as blanks. Dermal loss from the hair was not collected, and subjects were instructed to pull their hair up to prevent contamination. In addition, dermal loss from the hands was not collected to decrease variability due to contamination during the normal daily activities. Subjects were asked to wash their hands as necessary during the test and to wipe off the sweat from the face with the inner part of the suit to collect any sweat dripping from the face. Dermal loss from feet was collected using the chemically treated socks. Great care was taken to avoid covering an area of the body that is not normally covered with the purpose of measuring the usual dermal loss of an individual during a 24-h period.

After 24-h, subjects washed their hands with DI water to avoid contamination and proceeded to undress inside a plastic bag and rinse with approximately 950 ml of 0.003% polyoxethylene 23-lauryl ether detergent using a chemically treated washcloth and then with 1900 ml of DI water inside the plastic bag. Four 10-ml aliquots were collected from the rinse. The clothing, washcloth, and towel were stored in a plastic bag for later analysis. The subjects dressed with regular clothing, and then proceeded with the 24-h patches.

The clothing and towels used were acid washed in 12 L of 0.1-N acetic acid for 24-h in acid washed containers. After 24-h, 2 × 10-ml aliquots were collected for electrolyte analysis. A second acid wash was performed using a 24-h soak to test if all the electrolytes (especially sodium) were effectively removed by the first wash. Two 10-ml tubes aliquot were collected. The sodium concentration in the second rinse was 10% of the total sodium loss, therefore, this second rinse was included in the total sodium loss in sweat.

Although sweat, dead skin, and insensible water loss could all contribute to dermal electrolyte losses from the body surface, dead skin was removed from the body previous to each test thus minimizing contribution of exfoliated skin.

24-Hour Patch Dermal Loss Collection

The patches were applied to the skin immediately at the end of the 24-h whole-body dermal loss collection. The patches were not used simultaneously with the whole-body
washdown technique to prevent obstruction of dermal electrolyte loss between the methods. Eight rayon cellulose patches (Johnson & Johnson, Skillman, NJ, USA) were applied to the skin and covered with breathable paper (Fisher, PA, USA) to prevent contamination. A breathable paper was used to more accurately compare it to the whole-body washdown technique, in which a breathable suit material was used. Retaining moisture in the dermal loss was not necessary because the objective of the study was to compare total electrolyte secretion and not concentration. Hypoallergenic tape (Johnson & Johnson, Skillman, NJ, USA) was used to secure the 4 sides of the patches to the skin. Two patches were applied at each of the following sites:

- Lower back, at the level of the waist (right and left of the spine)
- Upper back, between shoulder blades (right and left of the spine)
- Inner arm (left and right), between the wrist and elbow
- Inner leg (left and right), between the knee and hip

The patch was 7.62 × 7.62 cm, and it covered a body surface area (BSA) of 58 cm². Subjects were instructed to follow the same daily activity pattern from the whole-body dermal loss collection. After 24-h, each patch was removed and stored in a labeled bag. The area covered by the patch was rinsed thoroughly with a chemically treated washcloth soaked in 0.003% polyoxethylene 23-lauryl ether detergent. Great care was taken to avoid spills and to avoid rinsing other areas not covered by the patch. The washcloth was stored along with the patches for later analysis.

The washcloth and the patches were later individually soaked in 300 ml of 0.1-N acetic acid solution for 24-h in acid washed containers, and 2 × 10-ml aliquots were collected. A second acid wash was performed for a subsequent 24-h to test if all the sodium was effectively removed by the first wash. The sodium concentration in this second rinse was only 0.038 mg, which represents 3% of the total sodium lost through patches; therefore, only the analysis of the first rinse was included.

The following equation was used to project from 24-h patch dermal loss to whole-body dermal loss by the ratio of surface area covered by the patch to whole BSA:

$$\frac{\text{Dermal loss (X)}_{\text{patch}} / \text{BSA}_{\text{patch}}}{\text{BSA}_{\text{whole body}}}$$

To calculate BSA, DuBois and DuBois formula was used (18), by the following equation: BSA (m²) = 0.20247 × Height (m)⁰.⁷²⁵ × Mass (kg)⁰.⁴²⁵. Since hair and hands were not included, BSA was adjusted by 9% to represent the actual BSA used for dermal loss collection (4% for hair and 5% for both hands).

**Analysis**

Dermal loss samples and dietary composites were measured for sodium, potassium, calcium, magnesium, iron, and copper by Atomic Absorption Spectrophotometry (AAS) (Perkin Elmer, 5100 PC, Norwalk, CT, USA).

Student t test was used to assess if electrolyte dermal loss from left and right patches were significantly different from each other. To test for differences between patch sites, a one-way analysis of variance and the Least Significance Difference multiple range post hoc analysis were used. Pearson correlation coefficients were
obtained to describe the relationships between electrolyte dermal losses from each patch site with the whole-body method. When Pearson correlations were significant, the regression equations were used to predict dermal loss from patch site to whole body. For non-normally distributed data, the log (base 2) transformation was applied; using the natural log or the log (base 10) did not transform the data. All means are reported with $\pm SD$. Statistical significance was set at $p < .05$. The Statistical Analysis System (SAS Institute, Cary, NC, USA) program and Microsoft Excel for Windows 2000 was used for all the statistical analyses.

**Results**

Table 1 shows the subject characteristics. Daily activity during the dermal loss trials was different among subjects but similar within subjects during the 2 testing days. For example, one subject reported 8 h of sleep, 9 h of sitting (sedentary), 6 h of standing (slight), .5 h of rope jumping, and .5 h of house cleaning (moderate) during each 24-h period, which resulted in an activity index score of 29.

Mean electrolyte loss during the 24-h whole-body washdown collection is shown in Table 2. Iron and copper levels were undetectable by the instrumentation used. Total electrolyte dermal loss data is presented but not concentration, as volume of dermal loss was not measured. Dermal electrolyte loss from 24-h whole

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>28.0 ± 5.0</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>70.5 ± 14.3</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>1.7 ± 0.1</td>
</tr>
<tr>
<td>Body surface area (m²)</td>
<td>1.82 ± 0.2</td>
</tr>
<tr>
<td>Activity level (index score)</td>
<td>31.6 ± 4.4</td>
</tr>
</tbody>
</table>

**Table 2  Mineral Loss From 24-hour Whole Body Sweat Collection (mg/d)**

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Mean ± SD</th>
<th>CV (%)</th>
<th>% of intake</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium</td>
<td>120.6 ± 124.4</td>
<td>103.1</td>
<td>12.9</td>
</tr>
<tr>
<td>Potassium</td>
<td>132.8 ± 87.0</td>
<td>65.5</td>
<td>7.5</td>
</tr>
<tr>
<td>Calcium</td>
<td>102.6 ± 22.3</td>
<td>21.7</td>
<td>14.7</td>
</tr>
<tr>
<td>Magnesium</td>
<td>35.2 ± 12.7</td>
<td>36.2</td>
<td>23.1</td>
</tr>
</tbody>
</table>
body represented a small amount from dietary intake, except for magnesium, which represented approximately one fourth of the total intake.

Dermal electrolyte loss from the different 24-h patches is shown in Figure 1. There were no significant differences between the left and right patches, and between the patches at the different sites for any of the electrolytes analyzed, even though potassium loss from the legs was about half compared to other sites. Further analysis revealed that dermal potassium loss was not normally distributed, but after transforming the data, there were still no differences among sites. There was a positive correlation between dermal potassium loss from the leg patches ($r = 0.81$, $p < .05$), and a trend between arm patches ($r = 0.80$, $p = .06$), upper back patches ($r = 0.78$, $p = .06$), and all patches combined ($r = 0.77$, $p = .07$) with whole body. No significant correlations were found for sodium, calcium, or magnesium.

Projections from patches to whole body by the ratio of BSA covered by suit to patch are shown in Figure 2. Compared to dermal loss from the whole-body washdown technique, the estimation to whole body from patches is 3.5X higher for sodium loss from arm and upper back patches and 3X from legs and lower back patches; for calcium, it was 3X higher from arms and legs and about 4X higher from the back patches; and for magnesium, it was 4X higher from all of the patches. For potassium, the estimation from patches, particularly from leg patches, to whole body are very

![Figure 1 — Dermal electrolyte loss from different 24-h patches. Average dermal electrolyte loss at each patch site: left and right arm, left and right leg, left and right upper back, and left and right lower back. There were no statistically significant differences between the left and right patch within site or between any of the different sites (mean ± SEM).](image-url)
similar to the whole-body washdown technique. Therefore, the following regression equation could be used to predict potassium dermal loss from leg patches to total body: Total whole body dermal potassium (mg/d) = \( (200.37 / \text{H11003 Dermal potassium from leg patches}) - 18.388 \). If all the patches combined are used to estimate whole body, then the estimation becomes 1.5X and 1.6X higher for sodium and calcium, and 1.8X higher for magnesium. In addition, projected sweat loss from all patches was not significantly different from the actual whole-body washdown technique, except for magnesium.

The resulting error ranges for estimating whole-body dermal loss from patches was 7% for potassium to 10% for sodium and 20% for calcium and magnesium.

**Discussion**

Dermal electrolyte loss was quantitatively measured by two methods during 24-h in young adult females. Whole-body dermal loss was collected using cotton pants, long sleeve shirt, underwear, and socks, a previously used, but time intensive method (1–6, 19), which has been validated in men for electrolyte sweat loss (2). Regional sweat was collected using rayon-cellulose patches from the arms, legs, upper back, and lower back, a less time consuming method, which has been validated in men for sweat loss for short periods of time under different conditions (10) and long periods of time at rest (13, 20).

![Figure 2 — Projections of dermal electrolyte loss from patches to whole body. Whole body was measured by the whole-body washdown technique in 24 h. Projections were calculated from combining left and right patches by the following equation: Sweat (X) patch / BSA patch × BSA whole body (mean ± SEM).](image-url)
In the present study, exercise was measured but not controlled during the testing days. However, the focus of this paper was to compare between methodologies (patch vs. whole-body suit) within subjects. Therefore, it is not relevant if all subjects performed the same level of activity during the 24-h period but that it was maintained between testing days within subjects.

Dermal sodium loss from the whole-body technique represented 10% of dietary intake, potassium dermal loss represented 7% of intake, and calcium and magnesium dermal loss represented about 20% of intake. Carr et al. (4) also measured whole-body sweat in male subjects for 24-h during sedentary activity in a similar way as in our study and found that sweat sodium was similar (42–154 mg/d sodium), but calcium secretion was 6X lower than in our study (8–21 mg/d calcium). Heer et al. (8) found lower whole-body sweat sodium in males (66 ± 8 mg/24 h and 77 ± 7 mg/24 h) studied under controlled chambers while consuming a low or high sodium diet (1.1 g/d or 4.6 g/d Na, respectively) compared to our study. This lower sodium sweat loss compared to our study could be attributed to the complete sedentary activity level of their subjects, compared to our study, in which subjects were free-living. No other study has reported potassium and magnesium sweat loss under similar conditions to our study. However, several studies have measured sweat electrolyte loss using the whole-body washdown technique in men with the use of heat and exercise to stimulate sweat with widely different results compared to our study (6, 7, 19). Since sweat electrolyte losses vary considerably depending on the methods used, ambient temperature, and activity level, among others, the results of the present study falls within a normal broad range.

We did not find significant differences in the electrolyte content of dermal loss among the patches placed in the arms, legs, upper and lower back. In addition, the left and right patches had similar electrolyte loss. In contrast, other studies have found that sweat varies depending on the region of the body studied. Sweat sodium has been found to be highest in the chest patches compared to those in the back and mid-upper arm, but no difference was found with potassium (6). Moreover, the number of active sweat glands from the forearm has been found to be higher than the back but lower than the forehead (11). However, these studies were performed during intense exercise and heat stress. Perhaps some sweat glands are stimulated more than others with intense exercise and heat but respond the same without these stimuli. Additionally, since most of these studies were performed in men, an alternative explanation is that women sweat more uniformly around the body.

This study is the first to compare projected whole-body dermal electrolyte loss from patches against direct measures of whole-body dermal electrolyte loss during a 24-h period in women. Projections from the patch at different sites to whole body (Figure 2) showed that electrolyte loss measured at regional dermal sites is considerably higher compared to the whole-body washdown technique, except for potassium loss from leg patches. The greater dermal electrolyte content from patches may occur because the patch covers the skin and creates a different environment. The local skin temperature or humidity could be raised leading to a higher electrolyte dermal concentration and different sweat composition (6, 12). However, in the present study when all the patches are combined, the estimation significantly improves, probably due a larger surface. Similarly, Cohn et al. (3) found that when comparing sweat from a regional area (arm) using sweat collection bags versus the whole-body washdown technique, sodium concentration was about three-fold higher (736–1628 mg/L) in the arms compared to whole body (244–658 mg/L) during 1 h.
The present study did not measure concentration, but it found that sodium loss from individual patches were three-fold higher than whole body from projections. Others have also found higher sweat sodium secretion from patches (6, 7, 12), but lower potassium (6, 12), compared to the whole-body technique. Therefore, our results in women are consistent with studies performed in men.

Despite the differences between methods, for most electrolytes, we observed that dermal potassium loss from the leg patches were significantly correlated with whole-body dermal loss, and a regression equation could be developed. No correlation was found with the other electrolytes. Potassium has been found to be consistently recovered from the patch during recovery tests, with high reproducibility compared to other electrolytes (21), insensitive to subject age (22), hydration status (23), and dietary potassium intake (24). In addition, the ionic composition of sweat has been suggested to vary differently for each electrolyte (12). Therefore, the amount of potassium lost in sweat appears to be independent of many factors and could be used to project from patch to whole body.

In conclusion, this study suggests that dermal patches overestimate losses in comparison to those measured by the whole-body technique, except for potassium, but if several patches are used, the estimation to whole body improves. In addition, this study serves as the first reference, albeit on a small number of subjects, for 24-h dermal electrolyte loss in young adult females under similar conditions reported here. This reference data could be useful in accounting for losses in metabolic balance studies or to compare to losses induced by environmental conditions or exercise.

References


