Two methods for estimating body surface area in adult amputees

PHILIP M. COLANGELO, DENNIS W. WELCH, DARRYL S. RICH, AND LOUIS P. JEFFREY

Abstract: Two methods for estimating body surface area (BSA) in adult amputees were developed. BSA in sq m was determined in 42 healthy, nonamputee men and women by summing the surface areas of individual body parts obtained using geometric measurements (BSA\text{meas}) and by an equation using height and weight (BSA\text{calc}). Linear regression analysis was used to determine correlations between BSA\text{meas} and BSA\text{calc} and between BSA\text{meas} and surface-area measurements of individual body parts (BSA\text{part}). The percentages of total BSA contributed by individual body parts in each subject were determined by the ratio of BSA\text{part} to BSA\text{meas}, and these percentages were compared with the corresponding percentages for body parts using the "Rule of Nines."

BSA\text{calc} and BSA\text{meas} were significantly correlated, as were BSA\text{part} and BSA\text{meas}. Regression analysis of BSA\text{part} versus BSA\text{meas} yielded an equation for each measured body part that allowed calculation of BSA\text{part} without direct measurement. BSA\text{part} expressed as a percentage of total BSA differed from the percentage of BSA used in the "Rule of Nines" by a mean of 12.4–32% depending on the body part. Two methods of estimating BSA in amputees were proposed based on deduction of the surface area of the amputated part (calculated from the regression equation for BSA\text{part} or as a percentage of total BSA) from total BSA\text{calc} in adult amputees.

The two methods developed in this study for estimating BSA may be useful in determining drug dosages in adult amputees and may provide more accurate information in burn therapy. Further studies are needed to validate the clinical application of these methods.

Index terms: Body surface area; Calculations; Dosage; Equations; Height; Methodology; Weight


Body surface area (BSA) is frequently used to calculate dosages of certain drugs such as the aminoglycosides and various cancer chemotherapeutic agents. Evidence in the literature also indicates that the clearance of certain drugs may best be adjusted on the basis of BSA rather than body weight. Over the years, numerous methods for determining BSA in man have been described. Both direct measurement and simpler means, such as calculating BSA from height and weight, have been employed. With the passage of time, many of these methods of calculation have been discarded. However, the DuBois and DuBois equation of 1916 for BSA based on height and weight is still considered a valid method for calculation of body surface area in adults.

Recently, Haycock and associates have shown that the equation of DuBois and DuBois underestimates surface area in newborns and infants by about 6 to 8%. Consequently, these investigators derived a geometric method and an equation using height and weight that was equal in accuracy to that of DuBois and DuBois for adults and more accurate for infants and children. Haycock et al. constructed nomograms to a segment from a sphere to a segment of a limb to determine BSA.

The geometric surface area representation has beenburned into grafts using a device that allows precise measurement of the outlined area. Thus, a method has been introduced for calculating a "averaged" portion of a patient.

The method was developed in an experimental study:

1. T
2. O
3. B
4. A
5. M

Metho
grams using their height–weight equation, which can be used to compute BSA for all the age groups mentioned. The method used to determine BSA by Haycock et al. involved geometric measurements. In this method, the trunk and limbs were reduced to a set of cylinders with the head represented by a sphere. Unfortunately, only summary data were presented so that the relative contribution of each limb or part of a limb to the total BSA could not be determined. Hence, the effects of amputation on BSA could not be determined using this method.

The “Rule of Nines” method, in which various sections of the body (e.g., entire arm, posterior surface of each leg, anterior surface of each leg) each represent approximately 9% of the total BSA, has been advocated in determining the extent of burns. This method has been used without verification of its validity in BSA estimations in amputees at many institutions. However, this method is limited in not allowing for an estimation of BSA if the amputee is missing, for example, only a hand, lower arm, or lower leg.

Body surface area is often used by the pharmacist to determine drug dosage, which is usually calculated using 1.73 sq m as the reference BSA for the “average” patient. A review of the literature revealed no published methods for accurately determining BSA in amputees, nor has there been any proven method described to adjust drug doses in patients with decreased BSA, such as amputees.

The primary objective of this study was to derive a method for estimating BSA in adults following amputation (BSA_AMP). The resultant BSA_AMP would then be useful for adjusting drug dosage regimens in such patients. Specifically, the objectives of this study were as follows:

1. To repeat the study of Haycock et al. with emphasis on the geometric determination, in normal subjects, of the surface area of individual body parts and of the body as a sum of the individual parts;
2. To formulate a method (with two variations) for calculating the surface area of individual body parts as a function of total BSA;
3. To evaluate the relationship between measured BSA and predicted BSA computed from height and weight, as an index of the reliability of predicted BSA for routine clinical use; and
4. To compare the formulated methods against a method based on the “Rule of Nines.”

Methods

A total of 42 healthy men and women from the department of pharmacy staff at our hospital were studied. Body surface area was determined using the two methods described by Haycock and coworkers in 1978. Measurements (e.g., length and circumference) of each body part were taken as described by Haycock et al., and surface area of each body part (SA_part) was determined using the same geometric equations that they used (Appendix). Each subject’s height and weight were measured, as were the following body parts: the head, neck, trunk, index finger, upper arm, lower arm, thigh, lower leg, and foot. Our study also included measurement of each subject’s hand so that the surface area of the hand could be calculated.

Total measured BSA (BSA_meas) was determined from the sum of the surface areas for the head, neck, trunk, upper arm (X2), lower arm (X2), index finger (X10), thigh (X2), lower leg (X2), and foot (X2). The measurement for the hand alone was not included in the calculation of the total BSA_meas since Haycock and associates included this body part as contributing to the surface area of the entire lower arm (i.e., the length measured from the olecranon to the tip of the 4th metacarpal). All measurements were performed by the same individual on all subjects using a nonelastic tape with the subjects standing.

The second method for determining BSA (BSA_calc) was based on the subject’s height and weight, using the following equation of Haycock et al. for surface area in infants, children, and adults:

\[
SA = \frac{W^{0.5379} H^{0.3964}}{0.024265}
\]

(1)

where SA is surface area in sq m, Wt is weight in kg, and Ht is height in cm. As an additional source of comparison, BSA was calculated according to the method of Dubois and Dubois:

\[
SA = \frac{W^{0.425} H^{0.725}}{71.84}
\]

(2)

where SA is surface area in sq cm, Wt is weight in kg, and Ht is height in cm.

The correlation between the values for BSA_calc (equation 1) and BSA_meas (geometric method) was analyzed by linear regression techniques and statistically compared using Student’s t test for paired data. The correlation between the values obtained for BSA_meas and SA_part was also analyzed using the same statistical methods, and the resulting regression equations were used to calculate SA_part based on BSA_meas.

The ratios of SA_part to BSA_meas for each subject were calculated to determine the percentage of total BSA represented by each body part. These percentages were then compared using Student’s t test for paired data with the percentages of total BSA represented by individual body parts using the “Rule of Nines.”

Statistical calculations were performed on a Radio Shack TRS-80 Model I microcomputer using a statistical package developed in-house by our data processing department. In all cases, an alpha level of 0.05 was used to determine statistical significance.

Results

The characteristics of the 42 subjects studied are shown in Table 1. Also shown are the BSAs calculated from the equations of Dubois and Dubois, and of Haycock et al., which used height and weight...
Table 1. Characteristics and Body Surface Areas of Study Population (n = 42)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean ± S.D.</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient Characteristics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (yr)</td>
<td>30.1 ± 5.7</td>
<td>20–44</td>
</tr>
<tr>
<td>No. of men</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>Height (cm)</td>
<td>174.93 ± 9.80</td>
<td>162–199</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>77.5 ± 14.0</td>
<td>52–122</td>
</tr>
<tr>
<td>Body Surface Area (sq m)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Method of DuBois and DuBois²</td>
<td>1.93 ± 0.20</td>
<td>1.47–2.57</td>
</tr>
<tr>
<td>Method of Haycock et al.¹²</td>
<td>1.96 ± 0.22</td>
<td>1.49–2.67</td>
</tr>
<tr>
<td>Method of Haycock et al.¹²</td>
<td>2.05 ± 0.22</td>
<td>1.51–2.75</td>
</tr>
</tbody>
</table>

Figure 1. Correlation of measured BSA versus calculated BSA. The regression equation for the line is \( y = 0.974x + 0.145 \) (\( r = 0.957; n = 42; df = 40; t = 20.91; \) RMS scatter = 0.066 sq m).

Table 2. Linear Regression Analysis of \( SA_{part} \) and BSA\(_{meas} \) (n = 42)

<table>
<thead>
<tr>
<th>Body Part</th>
<th>Regression Equation (sq m)</th>
<th>Correlation Coefficient ( r )</th>
<th>RMS Scatter (sq m)</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Index finger</td>
<td>( SA_{part} = (0.0027) BSA_{meas} + 0.0003 )</td>
<td>0.689</td>
<td>0.0066</td>
<td>6.01</td>
</tr>
<tr>
<td>Hand + 5 fingers</td>
<td>( SA_{part} = (0.0243) BSA_{meas} + 0.0075 )</td>
<td>0.785</td>
<td>0.0044</td>
<td>8.02</td>
</tr>
<tr>
<td>Lower arm</td>
<td>( SA_{part} = (0.0414) BSA_{meas} + 0.0030 )</td>
<td>0.889</td>
<td>0.0049</td>
<td>12.26</td>
</tr>
<tr>
<td>Upper arm</td>
<td>( SA_{part} = (0.0666) BSA_{meas} + 0.0140 )</td>
<td>0.829</td>
<td>0.0101</td>
<td>9.39</td>
</tr>
<tr>
<td>Thigh</td>
<td>( SA_{part} = (0.0909) BSA_{meas} + 0.0410 )</td>
<td>0.634</td>
<td>0.0275</td>
<td>5.19</td>
</tr>
<tr>
<td>Lower leg</td>
<td>( SA_{part} = (0.0649) BSA_{meas} + 0.0093 )</td>
<td>0.857</td>
<td>0.0082</td>
<td>11.42</td>
</tr>
<tr>
<td>Foot</td>
<td>( SA_{part} = (0.0315) BSA_{meas} + 0.0008 )</td>
<td>0.760</td>
<td>0.0062</td>
<td>7.39</td>
</tr>
</tbody>
</table>

\( ^a \) All correlations were significant based on Student’s t test for paired data (\( p < 0.05; \) df = 40).

\( ^b \) Includes hand but not fingers.

The excellent correlation (\( r = 0.96 \)) between BSA\(_{calc} \) and BSA\(_{meas} \) (Figure 1) indicates that the study was successful in reproducing the previous methods and results of Haycock et al. and implies that our calculations of \( SA_{part} \) used to determine BSA\(_{meas} \) were similar. Furthermore, the fact that the
Table 3.
Surface Area of Individual Body Parts (SA_{\text{part}}) Expressed as a Percentage of Total Measured BSA (BSA_{\text{ meas}})

<table>
<thead>
<tr>
<th>Body Part</th>
<th>Women (n = 7)</th>
<th>Men (n = 35)</th>
<th>Overall (n = 42)</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Index finger</td>
<td>0.32 ± 0.04</td>
<td>0.34 ± 0.03</td>
<td>0.34 ± 0.03</td>
<td>0.28–0.40</td>
</tr>
<tr>
<td>Hand plus 5 fingers</td>
<td>2.65 ± 0.19</td>
<td>2.83 ± 0.21</td>
<td>2.80 ± 0.22</td>
<td>2.36–3.35</td>
</tr>
<tr>
<td>Lower arm(^b)</td>
<td>3.80 ± 0.18</td>
<td>4.04 ± 0.23</td>
<td>4.00 ± 0.24</td>
<td>3.55–4.44</td>
</tr>
<tr>
<td>Upper arm</td>
<td>5.66 ± 0.53</td>
<td>5.94 ± 0.44</td>
<td>5.90 ± 0.52</td>
<td>4.73–6.88</td>
</tr>
<tr>
<td>Thigh</td>
<td>12.55 ± 1.44</td>
<td>11.80 ± 1.28</td>
<td>11.89 ± 1.33</td>
<td>9.77–15.50</td>
</tr>
<tr>
<td>Lower leg</td>
<td>6.27 ± 0.49</td>
<td>5.99 ± 0.36</td>
<td>6.04 ± 0.40</td>
<td>5.11–7.15</td>
</tr>
<tr>
<td>Foot</td>
<td>2.94 ± 0.32</td>
<td>3.15 ± 0.29</td>
<td>3.11 ± 0.30</td>
<td>2.54–3.93</td>
</tr>
<tr>
<td>Head</td>
<td>5.11 ± 0.68</td>
<td>4.66 ± 0.45</td>
<td>4.73 ± 0.52</td>
<td>3.82–6.33</td>
</tr>
<tr>
<td>Neck</td>
<td>2.64 ± 0.26</td>
<td>2.88 ± 0.28</td>
<td>2.83 ± 0.29</td>
<td>2.15–3.58</td>
</tr>
<tr>
<td>Trunk</td>
<td>26.66 ± 1.89</td>
<td>27.48 ± 1.79</td>
<td>27.27 ± 1.78</td>
<td>24.02–32.55</td>
</tr>
</tbody>
</table>

\(^a\) Reported as mean ± S.D.
\(^b\) Includes hand but not fingers.

Table 4.
Comparison of Methods for Determining Percentage of BSA Represented by Individual Body Parts

<table>
<thead>
<tr>
<th>Body Part</th>
<th>Calculated(^a)</th>
<th>“Rule of Nines” method</th>
<th>Mean Difference in BSA(^a) (sq m)</th>
<th>% Difference</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arm</td>
<td>11.6</td>
<td>9</td>
<td>-0.08</td>
<td>29</td>
<td>28.5</td>
</tr>
<tr>
<td>Leg</td>
<td>21.0</td>
<td>18</td>
<td>-0.05</td>
<td>12.4</td>
<td>5.86</td>
</tr>
<tr>
<td>Trunk</td>
<td>27.3</td>
<td>36</td>
<td>0.18</td>
<td>32</td>
<td>31.99</td>
</tr>
<tr>
<td>Head and neck</td>
<td>7.5</td>
<td>9</td>
<td>0.03</td>
<td>20</td>
<td>13.55</td>
</tr>
</tbody>
</table>

\(^a\) Determined by summing mean percentages of BSA of individual body parts from Table 3 where appropriate; e.g., arm = lower arm + upper arm + (index finger × 5).

\(^b\) All differences were significant based on Student’s t test for paired data (p < 0.05).

This subject’s adjusted BSA (BSA_{\text{amp}}) in sq m would be calculated as follows:

\[
BSA_{\text{amp}} = BSA_{\text{meas}} - SA_{\text{part}} = 2.1462 - 0.1273 = 2.0189
\]

It is noteworthy that these regression equations were derived based upon comparison of SA_{\text{part}} with BSA_{\text{meas}} and not with BSA_{\text{calc}}. However, because of the correlation coefficient of 0.957 resulting from the comparison of BSA_{\text{meas}} and BSA_{\text{calc}} the latter method may also be used to determine BSA_{\text{amp}}. This hypothesis was in fact tested using the SA_{\text{part}} equation for the lower arm. The values for SA_{\text{part}} for the lower arm were calculated using BSA_{\text{calc}} instead of BSA_{\text{meas}} in the regression equation. These values were then compared using linear regression analysis with the values for SA_{\text{part}} for the lower arm as actually measured in this study. The resulting correlation coefficient was 0.877 (versus 0.889 from Table 2). If the method of Dubois and Dubois for calculating BSA is used, the correlation would be slightly less. Hence, the method of Haycock et al. for determining BSA is preferred to the method of Dubois and Dubois when estimating SA_{\text{part}}, although it is not required.

A second way to determine BSA_{\text{amp}} is to use the mean percentage of total BSA contributed by the particular body part (Table 3). Using the same ex-
ample as above, the %BSA for the lower arm plus five fingers would be calculated as follows:

\[
%\text{BSA} = 4.00 + 5(0.34) = 5.70
\]

The BSA_{amp} in sq m for this subject would then be calculated as follows:

\[
\text{BSA}_{\text{amp}} = \text{BSA}_{\text{meas}} - (\text{BSA}_{\text{meas}})(%\text{BSA})
= 2.1462 - (2.1462)(0.0570) = 2.0239
\]

With this method it also follows that BSA_{calc} or another suitable nomogram can be used in lieu of the BSA_{meas}.

The percentages of BSA_{meas} that SA_{part} represents in each sex are also shown in Table 3. However, the differences in these values are probably not large enough to be of much practical concern.

It should be emphasized that the methods provided here are based on data derived from 42 healthy nonamputees and should be considered estimations. However, the method we used to determine BSA has been validated in a previous study. A more accurate method for determining BSA that is ethically feasible in 1984 has not been developed. The limitation of using this method in normal subjects versus actual amputees is only important if the morphological characteristics of amputees are substantially different from those of normal subjects. The authors believe this is highly unlikely. Furthermore, while 42 subjects may be considered a small sample size, the results achieved were significant and this number represents the largest sample size used to determine BSA in adults. (DuBois and DuBois used 33 subjects, and Haycock et al. used 19 adults.) However, the small sample size should be considered a limitation of the study.

It is important to note the intersubject variability of SA_{part} as a percentage of the total BSA (Table 3), despite the good correlation between SA_{part} and BSA_{meas}. Although not large, it emphasizes the need to consider these methods as estimations when calculating BSA in amputees or SA_{part} in any patient.

Perhaps another striking observation is the large contribution to BSA provided by the fingers. This makes sense considering how this increase the surface area of the intestine. One wonders if the accuracy of the BSA calculation could be improved by considering the toes separately. However, that question was beyond the objectives of this study.

Some institutions have empirically used the "Rule of Nines" to approximate BSA in amputees. Table 4 shows a comparison of the mean percentage of measured surface area for various body parts versus the "Rule of Nines." Although the differences are significant, the practical importance of these differences is unknown. Certainly, the "Rule of Nines" does not allow for the determination of BSA in cases of partial limb amputation, which is this method's major limitation over the ones proposed by this study.

### Conclusion

The two methods developed in this study for estimating BSA may be useful in determining drug dosages in adult amputees and may provide more accurate information in burn therapy. Further studies are needed to validate the clinical application of these methods.

### References


### Appendix—Geometric Calculation of Surface Areas of Individual Body Parts

Three basic geometric equations were used to calculate surface areas of individual body parts from geometric measurements. The area of a sphere, minus the cross-sectional area of an attached cylinder, was used for determining the surface area of the head as follows:

\[
4\pi \left( \frac{C_1}{2\pi} \right)^2 - \pi \left( \frac{C_2}{2\pi} \right)^2
\]

where \(C_1 = \) head circumference and \(C_2 = \) neck circumference.

The area of a cylinder, without including either end, was used to calculate surface areas for the neck, upper arm, lower arm, hand, thigh, and lower leg as follows:

\[
\text{(Length)} \times \text{(Circumference)}
\]

The area of a cylinder with the surface area of one end included was used to calculate surface areas for the trunk, index finger, and
Body surface area Reports

\[
\text{foot as follows:} \\
(\text{Length})(\text{Circumference}) + 4\pi \left(\frac{\text{Circumference}^2}{2\pi}\right)
\]

Measurements for length and circumference were determined as follows:

<table>
<thead>
<tr>
<th>Body Part</th>
<th>Length</th>
<th>Circumference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>Angle of mandible to sternomanubrial joint</td>
<td>Occipitofrontal Midpoint</td>
</tr>
<tr>
<td>Neck</td>
<td>Sternumanubrial joint to intertrochanteric line</td>
<td>Mean of nipple, umbilical, and intertrochanteric lines</td>
</tr>
<tr>
<td>Upper Arm</td>
<td>Acromion to olecranon</td>
<td></td>
</tr>
<tr>
<td>Lower Arm*</td>
<td>Olecranon to tip of fourth metacarpal</td>
<td></td>
</tr>
<tr>
<td>Hand*</td>
<td>Radialcarpus to tip of fourth metacarpal</td>
<td></td>
</tr>
<tr>
<td>Index Finger</td>
<td>Tip of second metacarpal to fingertip</td>
<td></td>
</tr>
<tr>
<td>Thigh</td>
<td>Greater trochanter to head of fibula</td>
<td></td>
</tr>
<tr>
<td>Lower Leg</td>
<td>Head of fibula to lateral malleolus</td>
<td></td>
</tr>
<tr>
<td>Foot</td>
<td>Calcaneum to tip of fourth toe</td>
<td></td>
</tr>
</tbody>
</table>

*Includes the hand.
*Differs from method by Haycock et al.,¹² which does not calculate the surface area of the hand.

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