A Linear Equation For Estimating The Body Surface Area In Infants And Children

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Abstract

Examination of published human body surface area (BSA) data discloses a linear relationship between BSA and weight in infants and children weighing between 3 and 30 kg. Application of linear regression analysis to published data results in a formula relating BSA in square centimeters and weight in grams:

BSA = 1321 + 0.3433* Wt.

INTRODUCTION

It is a frequent practice in anesthesiology and critical care medicine to estimate the human BSA. This determination is useful in several areas related to the body's metabolism, such as ventilation, fluid requirements, extracorporeal circulation, and drug dosages. The BSA may be estimated with a nomogram, which is a graphical rendering of a formula, or calculated by scientific calculator or computer. There is a risk when using a nomogram, since many in widespread use contain a graphical error (1). It has been reported that nomograms frequently underestimate the BSA of infants by about 8% (2). Because of this, physicians often depend upon elaborate formulas to establish BSA. However, the formulas most often used are too complex to mentally calculate; even a four-function calculator is insufficient due to the biexponential nature of the formulae. The earliest of these biexponential formulas, and arguably the one in most widespread use, is that of Dubois and Dubois, published in 1916 (3). Using a technique of coating or wrapping subjects with "gummed paper," they developed a formula for determining BSA. Unfortunately, these two investigators used only a few subjects in the development of this formula; they were dominantly male, two were deformed, and the only child included was "sickly." Because the authors failed to include a greater number of children, the formula of Dubois and Dubois may be considered undefined for those subjects with BSA of less than 0.6 meters squared.

A more complex formula, which still retains the fundamental biexponential structure of Dubois and Dubois' formula, was developed by Edith Boyd of the University of Minnesota and published in 1935 (4). She compiled height, weight, and BSA data from the published literature for 231 subjects, including a large number of children, infants, and fetuses. The methods used to measure the BSA included triangulation, surface integration, and various coating methods. The formula derived by Boyd is

BSA = Wt. ^(0.7285-0.0188 log Wt.)*Ht ^(0.3)*0.0003207

The complexity of this formula originates from the fact that fetuses, infants, and adults are three separate populations with very distinct shape-weight relationships. The attempt to write one equation that encompasses all size subjects from pre-term to adulthood necessitated such complexity. As such, Boyd's formula remains the most accurate in common use. However, it is quite inconvenient for use in emergent clinical situations. There are still occasions which necessitate estimating the BSA of infants and children at the bedside when a calculator may be unavailable. Therefore, a simple linear equation is offered, derived from published human BSA data for infants and children, which requires no more than a pencil and a scrap of paper or may even be calculated mentally.

METHODS

Data from 112 patients in the published literature as reported by Boyd (4) with weights between 3 and 30 kilograms were included in this study. Using the least squares method, linear regression analysis was applied to this data.

RESULTS

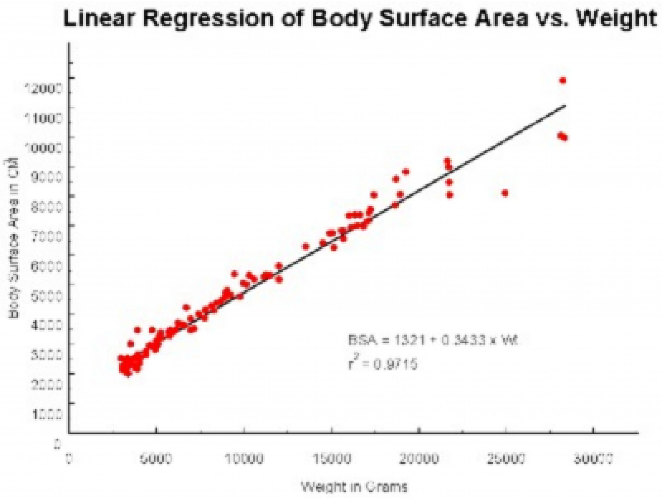
Linear regression between Boyd's weight and measured BSA yielded a formula of:

BSA = 1321 + 0.3433*Wt.

Figure 1: BSA related to weight for children and infants between 3-30 kg. Regression line and equation are given.

Figure 1

Scatter plot of BSA vs. Wt. with regression line



Then, Pearson's linear correlation was determined between measured and calculated BSA for these subjects, using both Boyd's formula and the linear regression formula. It was found that Pearson's linear correlation coefficient for measured BSA and the value calculated with Boyd's formula is 0.9857 ($p<0.001$). Pearson's linear correlation coefficient for measured BSA and the value calculated with the linear regression formula is also 0.9857 ($p<0.001$). The high correlation between the measured and calculated values justifies the use of this formula for infants and children.

DISCUSSION

The derived linear regression formula presented here is intended for use in applications which might be considered "non-critical" regarding accuracy implications, such as pump flows or fresh gas flows. In more "critical" applications, such as computations of a chemotherapeutic dosage, time should permit use of a scientific calculator and Boyd's formula.

A simplification of the expression derived by linear regression is

BSA = (Wt. + 4)/30

The units are different, weight being in kilograms and BSA being in square meters, and this equation is only valid for well-proportioned infants and children between the weights of 3 and 30 kg, as is the linear regression formula. However, this formula is much easier to remember and calculate mentally, and it yields nearly identical results to the more complex formula. In fact, the results differ by no more than 0.8-2.5% over the range of 3-30 kg.

In 1981, Lindahl and Okmian noticed a linear relationship between weight and BSA in their group of 179 patients ([5]). Although they produced a simple equation with a promisingly high correlation, they did not actually measure the BSA of their subjects. Rather, they calculated the BSA using the Dubois and Dubois method, which is undefined for children. This casts doubt on the validity of the linear relationship they found.

Jones et al. measured the BSA of 15 adult females of all body types by wrapping "aluminum baking foil" over the left side of subjects, and found a much higher correlation of BSA with weight than height. In fact, they developed a linear equation relating BSA to weight and upper calf circumference. These early results seem promising for both sexes "with a mean error of only -0.004 m^2." However, researchers admit the need for further testing among males of all ages, since data was only obtained from four young men ([6]).

Other formulas in common use for calculating BSA most often employ height and weight. Haycock's formula ([7]) is well known and has the advantage of being validated in newborn infants by Brion et al. ([8]), who calculated surface area from multiple linear measurements. Unfortunately, Haycock's formula is also biexponential in form with all the attendant difficulty in calculation that implies.

In 1954, Sendroy and Cecchini developed another formula for BSA estimation: "If the relationship for height and weight for human growth during the juvenile' period of fairly uniform rate of increase between ages 4-6 and 15-20 years be plotted on the graph of figure 2, the data from various sources (1,4) cluster about what is nearly a straight line. This relationship is also expressed in a familiar form of an equation approximately descriptive of the general trend in development when geometrical similarity of solid form is maintained, i.e.,

H = 43 W^0.333

where H and W are in terms of cm, and kg respectively." ([9])

This high correlation of BSA estimation from the linear regression formula with actual BSA measurements is justification enough for use when ease of computation is important. Of course, when time permits and an advanced scientific calculator or computer is immediately available, then most clinicians will likely choose the more complex Boyd formula.

These formulas were all developed from data gathered on subjects with dominantly European origins. Although frequently applied to other racial groups, there is little data to validate their use in those of Asian or African origin. In fact, at least one study of BSA in black Nigerians suggests that they overestimate the body surface area by 6-22% in this population ([10]). The inaccurate results produced by these formulas have been attributed to their failure to consider shape differences among races. Studies of Nigerian adults have found differences, such as greater limb length or lower average height and weight, when compared with results gained from European studies ([11]). Therefore, this formula should be used with caution for other racial groups.

This author has found the linear equation developed in this paper to be very useful in the acute operating room management of infants and children for the application of pump flows and fresh gas flows. These determinations are greatly expedited by the ease in use of a simple linear formula as presented here. The accuracy of this equation is adequate to justify its use in most non-critical cases.

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