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Formula and Scale for Body Surface Area Estimation in High-Risk Infants

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ABSTRACT

Advances in medical technology and the health sciences have lead to a rapid increase in the prevalence and morbidity of high-risk infants with chronic or permanent sequels such as the birth of early preterm infants. A suitable formula is therefore needed for body surface area (BSA) estimation for high-risk infants to more accurately devise therapeutic regimes in clinical practice. A cohort study involving 5014 high-risk infants was conducted to develop a suitable formula for estimating BSA using four of the existing formulas in the literature. BSA of high-risk infants was calculated using the four BSA equations (Boyd-BSA, Dubois-BSA, Meban-BSA, Mosteller-BSA), from which a new calculation, Mean-BSA, was arithmetically derived as a reference BSA measure. Multiple-regression was performed using nonlinear least squares curve fitting corresponding to the trend line and the new equation, Neo-BSA, developed using Excel and SPSS 17.0. The Neo-BSA equation was constructed as follows: Neo-BSA=5.520x$W^{0.5526}$x$L^{0.3800}$. With the assumption of the least square root relation between weight and length, a BSA scale using only weight was fabricated specifically for clinical applications where weight is more available in high-risk infant populations than is length. The validity of Neo-BSA was evaluated against Meban-BSA, the best of the four equations for high-risk infants, as there is a similarity of subjects in the two studies. The other formulas revealed substantial variances in BSA compared to Neo-BSA. This study developed a new surface area equation, Neo-BSA, as the most suitable formula for BSA measurement of high-risk infants in modern-day societies, where an emerging population of newborns with shorten gestational ages are becoming more prevalent as a result of new advances in the health sciences and new development of reproductive technologies. In particular, a scale for 400–7000 g body weight babies derived from the Neo-BSA equation has the clinical advantage of using only weight as a measurement, since length is often not feasible as a measurement due to the newborn's body posture. Further studies are required to confirm our findings for the application of Neo-BSA and the BSA scale (based on weight) for various populations and ethnicities under different clinical conditions.

Key words: *body surface area, high-risk infants, length, newborns, weight*

Introduction

Advances in medical technology and the health sciences have led to a rapid decrease in mortality as well as increases in the survival of high-risk infants that includes early preterm births. In Korea, the rate of preterm births increased from 3.8% in 2000 to 15.7% in 2006[1] as the rate of low birth weight (LBW) newborns delivered at acute tertiary hospitals increased from 15% in the 1980s to 25% in 2000[2]. This increase in LBW is a world-wide phenomenon of modern societies; in the United States, the rate of preterm births was 9.3% in 1981 and 12.5% in 2006[3]. Practicing health care professionals are being confronted by a substantial challenge to develop medical treatments and medical care protocols based on knowledge of specific body structure and function of high-risk infants. Body surface area (BSA) has become of significant interest to child-health care specialists and scientists for a variety of reasons, including the importance of anthropometric size, body aerodynamics and hydrodynamics[1,4] and drug metabolism and chemotherapy[5,6], with special considerations for total body water composition[7], transdermal insensible water loss[8], and thermoregulation[9] in high-risk infants.

Direct measurement of BSA of infants however, is not feasible in most cases considering its dependence on infant manipulation and use of multifaceted instruments,

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which increase energy consumption and expenditure in high-risk babies, for whom energy conservation can be vital to survival. As well, differences in geometric assumptions of the infant body and limbs[10,11] based on human life cycle variation, limits the application of the existing BSA formulas developed decades ago with little consideration for biometric shapes of high-risk infants. Given the significant variation in BSA estimation for full-term infants using popular formulas[11], the possibility that substantial errors are likely to occur in BSA estimation of preterm births or LBW infants is significant. Therefore, a study was undertaken to develop a more suitable formula for BSA estimation in high-risk infants including early preterm births and LBW babies that more accurately reflects their body biometrics and are more accurate for therapeutic use in clinical practice.

Materials and Methods

Participants

A cohort study was conducted to develop a suitable formula for BSA estimates using existing formulas in 5014 high-risk infants hospitalized in a level III Neonatal Intensive Care Unit (NICU) and nursery in two Korean University affiliated hospitals. Both hospitals, located in large urban areas, are national referral centers where high-risk infants are delivered with various conditions such as extremely LBW or early preterm births as early as at 24 weeks gestation (gestation age, GA). All newborns at the two sites were enrolled from August 2007 to July 2008. However, infants transferred from other hospitals, or those with multigestational or congenital skeletal disorders were excluded from the study because of their possible affect on BSA. The institutional review board of the hospital approved the study. In the 5014 subjects (54.6% male newborns), the mean GA was 37.8 weeks (range 23.5–42 weeks) with a mean body weight of 2994 g (range 480–6500 g) and a mean length of 49 cm (range 21–60 cm). Within the infant cohort 1424 (28.4%) were preterm births while 17 (0.3%) were post-term.

Study protocol

In order to develop a suitable formula for BSA estimation of high-risk infants, the study design involved several steps. First, using the existing BSA formulas as listed below, four BSA calculations were performed. These four formulas were selected based on their common use in the literature[12,13] or because they were derived using a pediatric sample, including stillborns[14,15]. Secondly, the fifth formula is an arithmetic mean of the four formulas below calculated as a Mean BSA, which can be considered a best measure of BSA since the four formulas have all been derived in independent studies[16]. When direct measurement of BSA (the žgold standard') is not possible the arithmetic mean of BSA can serve to accurately reflect BSA based on any given formula[11,17]. Third, variation in the four BSA formulas was evaluated against the Mean-BSA as the reference BSA for each gestational age. Fourth, the trend line for Mean-BSA was generated with a goodness-of-fitness in weight and length using a curve fitting model. Finally, the logarithm formula was arithmetically formulated using nonlinear least squares curve fitting corresponding to the trend line as a suitable BSA formula called, Neo-BSA, specifically for use among high-risk infants. In addition, with the assumption of the least squares root relation between weight and length, a BSA scale using only weight was developed for clinical practice where weight is more available compared to height for high-risk infants.

In order to minimize any influencing factors affecting body biometrics such as the amount of food intake or physiologic weight loss shortly after birth, birth weight in kg (*except in g for the Meban formula), and birth length (height) in cm were used for all calculation. Explorative data analysis with descriptive statistics, multiple regression analysis using a curve fitting model and logarithm function, ANOVA, and correlation was achieved with á=.05 in a two-tail test using Excel and SPSS 17.0.

Formula by Boyd:
$$\text{Boyd-BSA} = 4.688 \times W^{(0.8168-0.0154 \times \log W)}$$

Formula by Dubois:
$$\text{Dubois-BSA} = 71.84 \times W^{0.425} \times H^{0.725}$$

Formula by Meban*:
$$\text{Meban-BSA} = 6.4954 \times W^{0.562} \times H^{0.320}$$

Formula by Mosteller: $\text{Mosteller-BSA} = \sqrt{\frac{H \times W}{3600}}$

Results

Weight, lenght, and percent growth for gestational age

Table 1 shows the values for weight, length, and percent of growth of preterm infants by gestational age were calculated against the weight and length at 39–40 weeks (full term gestation). Weight and length of infants born at 24 weeks GA were 679 g and 31 cm respectively, corresponding to 21% and 62% of full-term growth. Weight reached up to 60% of full term growth, while height was almost 90% after 34 weeks GA. Both weight and length were positively correlated with GA (r=.752 and.773, p=.000, respectively).

BSA measurements and its variation using Mean-BSA

The BSA measurements using the four formulas above and the Mean-BSA are shown for each GA in Table 2. The smallest (725 cm^2 at 24 weeks GA) and the largest (2326 cm^2 at 42 weeks GA) BSA calculations among all measurements were produced by the Boyd-BSA. These five BSA measurements revealed that at 24 weeks GA about one-third and at 33 weeks GA about two thirds of BSA is attained, compared to full term gestation at 39–40 weeks as shown in Table 3. Since Mean-BSA served as the best reference BSA measurement, variations in per-

TABLE 1
PERCENT OF FULL-TERM WEIGHT AND LENGTH OF PREMATURE INFANTS BY GESTATIONAL AGE (GA) AT BIRTH (N = 5014)

GA	N (%)	Weight(gram)	Length(cm)	% of full-term Weight	% of full-time Length (%)
		X̄ (SD)	X̄ (SD)	X̄ (SD)	X̄ (SD)
24	7 (0.1)	678.6 (84.90)	31.1 (1.17)	20.7 (2.58)	61.8 (2.32)
25	16 (0.3)	855.1 (478.97)	34.1 (4.48)	26.0 (14.57)	67.9 (8.91)
26	13 (0.3)	943.4 (396.29)	33.9 (6.08)	28.7 (12.06)	67.3 (12.08)
27	24 (0.5)	1009.6 (305.45)	35.2 (3.61)	30.7 (9.29)	67.0 (7.18)
28	34 (0.7)	1208.0 (366.77)	37.6 (3.38)	36.7 (11.16)	74.6 (6.72)
29	27 (0.5)	1338.2 (482.25)	38.5 (3.73)	40.7 (14.67)	76.5 (7.42)
30	49 (1.0)	1321.4 (342.27)	38.6 (3.54)	40.2 (10.41)	76.7 (7.04)
31	48 (1.0)	1623.5 (409.07)	40.9 (3.13)	49.4 (12.44)	81.4 (6.22)
32	59 (1.2)	1716.0 (297.77)	42.1 (0.06)	52.2 (9.06)	83.8 (6.09)
33	72 (1.4)	1871.1 (423.16)	43.4 (2.73)	56.9 (12.87)	86.2 (5.43)
34	105 (2.1)	2170.1 (372.67)	44.9 (2.87)	66.0 (11.34)	89.3 (5.70)
35	143 (2.9)	2331.9 (510.77)	45.6 (2.74)	70.9 (15.54)	90.7 (5.45)
36	241 (4.8)	2528.6 (471.80)	46.8 (2.65)	76.9 (14.35)	93.1 (5.28)
37	584 (11.6)	2833.7 (487.76)	48.3 (2.41)	86.2 (14.84)	96.0 (4.80)
38	1059 (21.1)	3105.3 (459.04)	49.4 (2.25)	94.5 (13.96)	98.1 (4.47)
39	1168 (23.3)	3241.8 (425.13)	50.0 (2.00)	98.6 (12.93)	99.5 (3.97)
40	976 (19.5)	3342.5 (429.90)	50.6 (2.16)	101.7 (13.08)	100.7 (4.29)
41	371 (7.4)	3446.6 (491.19)	51.1 (1.97)	104.8 (14.94)	101.7 (3.91)
42	17 (0.3)	3423.2 (393.61)	50.9 (1.82)	104.1 (11.97)	101.1 (3.62)
Total	5014 (100)	2994.3 (683.20)	48.9 (3.68)	91.1 (20.78)	97.1 (7.31)

centile of BSA measurements by the other four formulas were examined against the Mean-BSA. As shown in Table 4, there were significant differences in the four BSA measurements for each GA (3.0886<F<16121.91, p<.039). Figure 1 illustrates a significant difference in the patterns of variation in BSA measurements by GA compared to Mean-BSA. As GA increased, variation of Boyd-BSA increased, while those of Dubois-BSA decreased, showing almost a 10% difference between the two measures (–5.1 to 5.1%) for full term gestation. Meban-BSA and Mosteller-BSA provided relatively less variation compared to Mean-BSA, which tended to decrease as GA increased.

Development of Neo-BSA

Since weight and height are the major determinants of BSA, curve estimation using the least squares methods in multiple regression was performed to reveal the relationship of Mean-BSA to weight and length. As a result, the trend line was constructed with the highest correlation coefficient between Mean-BSA and weight (Figure 2). Subsequently, a logarithm equation was formulated based on goodness-of-fit of the trend line between Mean-BSA and weight, which was named Neo-BSA$_w$. The same procedure was carried out for the equation for the trend line between Mean-BSA and length, which was named Neo-BSA$_h$ (Figure 3). These logarithm formulas are written as follows:

$$\text{Neo-BSA}_w = 10.602 \times \text{Weight}^{0.6561} \ (R^2=0.9937)$$

$$\text{Neo-BSA}_h = 0.5723 \times \text{Length}^{2.0976} \ (R^2=0.8763)$$

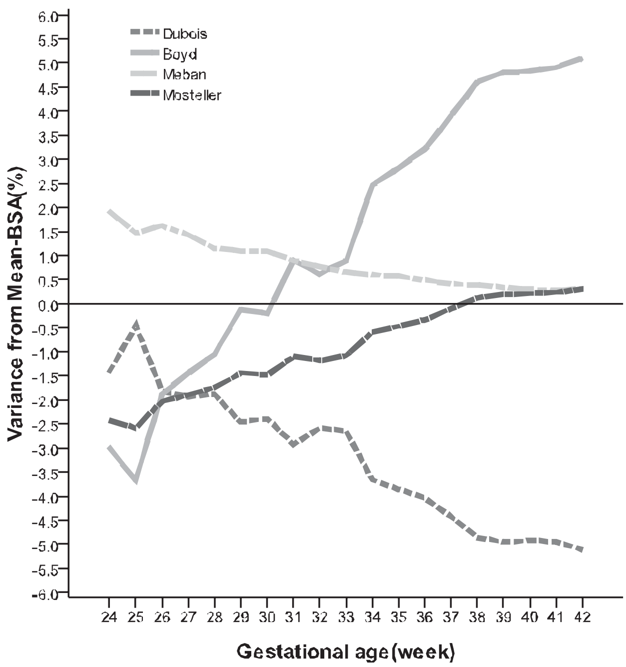

Fig. 1. Percent variance in BSA measurements compared to the Mean-BSA.

TABLE 2
BSA CALCULATION (in cm^2) OF THE SAMPLE (N=5014) USING FOUR BSA FORMULAS AND THE CALCULATED MEAN-BSA

GA	Boyd-BSA	Dubois-BSA	Meban-BSA	Mosteller-BSA	Mean-BSA
	$\overline{X}$ (SD)	$\overline{X}$ (SD)	$\overline{X}$ (SD)	$\overline{X}$ (SD)	$\overline{X}$ (SD)
24	724.8 (66.58)	761.0 (61.98)	761.0 (61.98)	765.1 (61.05)	746.7 (61.68)
25	840.5 (298.61)	861.6 (266.52)	879.4 (278.32)	889.2 (277.85)	867.6 (280.11)
26	907.7 (264.45)	885.7 (282.66)	914.9 (287.27)	919.9 (290.18)	912.0 (289.43)
27	960.6 (195.53)	947.7 (189.20)	980.0 (194.60)	984.9 (194.60)	966.7 (194.71)
28	1094.0 (216.08)	1065.7 (197.75)	1099.3 (211.48)	1115.8 (208.54)	1087.3 (212.39)
29	1171.7 (297.21)	1148.1 (247.2)	1194.2 (277.27)	1196.7 (267.79)	1181.8 (276.50)
30	1168.6 (205.21)	1140.3 (202.58)	1181.1 (209.67)	1185.9 (209.93)	1168.9 (211.44)
31	1355.2 (233.36)	1296.8 (205.70)	1349.3 (225.09)	1351.7 (219.70)	1337.8 (225.60)
32	1413.7 (179.10)	1343.9 (163.00)	1390.3 (168.55)	1396.3 (168.55)	1380.2 (169.93)
33	1501.2 (241.21)	1428.7 (185.21)	1479.0 (204.58)	1484.7 (198.81)	1469.6 (204,69)
34	1672.4 (209.00)	1577.8 (173.12)	1648.0 (181.78)	1647.6 (180.46)	1638.4 (183.16)
35	1757.4 (172.88)	1638.6 (213.35)	1716.0 (236.68)	1713.4 (229.69)	1706.6 (237.30)
36	1864.3 (246.27)	1729.4 (195.48)	1812.2 (213.62)	1809.8 (208.55)	1803.5 (214.57)
37	2022.4 (250.06)	1856.9 (192.00)	1952.6 (213.90)	1945.7 (206.90)	1944.6 (214.16)
38	2160.1 (228.18)	1960.7 (177.27)	2069.8 (197.32)	2058.7 (190.95)	2062.0 (197.89)
39	2227.2 (207.12)	2018.0 (157.59)	2131.6 (176.91)	2119.5 (170.40)	2124.3 (177.27)
40	2277.3 (208.30)	2060.5 (162.17)	2175.8 (178.36)	2164.1 (174.36)	2169.2 (179.32)
41	2325.6 (229.04)	2102.2 (167.68)	2219.2 (193.76)	2207.1 (184.17)	2213.1 (193.66)
42	2317.1 (188.15)	2090.4 (145.56)	2210.4 (161.35)	2196.76 (156.30)	2203.7 (162.01)
Total	2096.2 (359.02)	1917.6 (283.27)	2020.7 (310.11)	2011.6 (302.78)	2013.1 (311.41)

GA: gestational age in weeks; BSA: body surface area

By taking the logarithm of both sides of above equation, the equation can be expressed as a linear relationship. The log(BSA)-log(Weight)-log(Length) relationship was investigated by applying multiple regression analysis. Finally, the Neo-BSA formula using weight and length was constructed as follows:

$$\text{Neo-BSA}=5.52005\times W^{0.5526}\times L^{0.3800}$$

The lack of difference between Neo-BSA and Mean-BSA using a paired t-test (t=–.494, p=.621) and high correlation between two measurements (r=.997, p=.000) supported the validity of Neo-BSA against the reference Mean-BSA. Meanwhile, similarity and dissimilarity of the existing four formulas against Neo-BSA remains to be explored, considering that the Neo-BSA was formulated for the Mean-BSA, which was the mean of these four formula measurements. Correlation coefficients and Euclidean distance (ordinary distance between two points) were analyzed for similarity and dissimilarity of BSA measurements for the existing formulas compared to Neo-BSA. As presented in Table 5, Neo-BSA showed an almost perfect correlation with the other four formulas. However, Boyd-BSA and Dubois-BSA showed relatively substantial Euclidean distance against Neo-BSA, while Meban-BSA and Mosteller-BSA showed the least Euclidean distance (601.1 and 892.8 respectively). Therefore, in a geometric sense, Neo-BSA corresponds much more to Meban-BSA and Mosteller-BSA, while significant differences exist between Neo-BSA and Boyd-BSA and Dubois-BSA, irrespective of the similar patterns of BSA

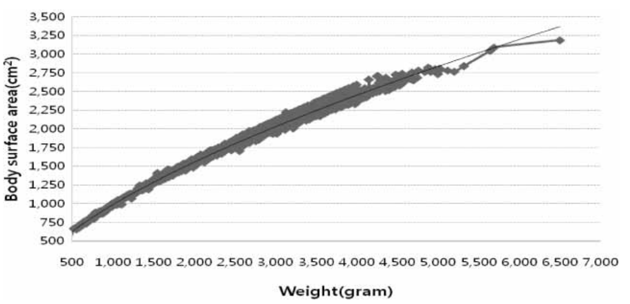

Fig. 2. Trend line of BSA by weight.

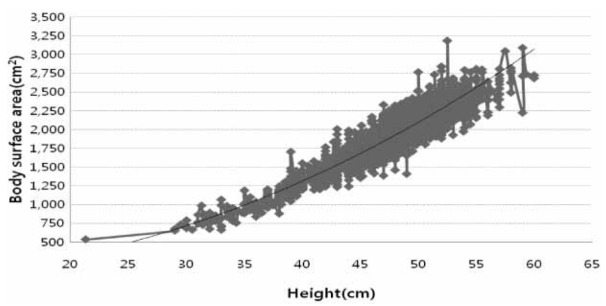

Fig. 3. Trend line of BSA by length.

TABLE 3
PERCENT CHANGE IN BSA BY GESTATIOAL WEEK FOR THE FIVE FORMULAS

GA	Boyd-BSA	Dubois-BSA	Meban-BSA	Mosteller-BSA	Mean-BSA
	$\overline{X}$ (SD)	$\overline{X}$ (SD)	$\overline{X}$ (SD)	$\overline{X}$ (SD)	$\overline{X}$ (SD)
24	32.2 (2.96)	36.1 (2.82)	35.4 (2.88)	35.8 (2.85)	34.8 (2.88)
25	37.3 (13.27)	42.3 (13.08)	40.9 (12.94)	41.6 (12.99)	40.5 (13.06)
26	40.3 (11.75)	43.5 (13.87)	42.5 (13.35)	43.0 (13.56)	42.1 (13.50)
27	42.7 (8.69)	46.5 (9.29)	45.5 (8.97)	46.0 (9.10)	45.1 (9.08)
28	48.6 (9.60)	52.3 (9.71)	51.1 (9.83)	51.7 (9.75)	50.7 (9.90)
29	52.1 (13.21)	56.3 (12.13)	55.5 (12.89)	55.9 (12.52)	55.1 (12.89)
30	51.9 (9.13)	56.0 (9.94)	54.9 (9.75)	55.4 (9.81)	54.5 (9.86)
31	60.2 (10.37)	63.6 (11.00)	62.7 (10.46)	63.2 (10.27)	62.4 (10.52)
32	62.8 (7.96)	66.0 (8.00)	64.6 (7.84)	65.3 (7.88)	64.4 (7.92)
33	66.7 (10.72)	70.1 (9.09)	68.7 (9.51)	69.4 (9.29)	68.5 (9.54)
34	74.3 (9.29)	77.4 (8.50)	76.6 (8.45)	77.0 (8.43)	76.4 (8.54)
35	78.1 (12.13)	80.4 (10.47)	79.8 (11.00)	80.1 (10.73)	79.6 (11.06)
36	82.8 (10.94)	84.9 (9.59)	84.2 (9.92)	84.5 (9.75)	84.1 (10.01)
37	89.9 (11.11)	91.1 (9.42)	90.8 (9.93)	90.9 (9.67)	90.7 (9.99)
38	96.0 (10.14)	96.2 (8.70)	96.2 (9.17)	96.2 (8.92)	96.2 (9.23)
39	99.0 (9.20)	99.0 (7.73)	99.1 (8.22)	99.1 (7.96)	99.1 (8.27)
40	101.2 (9.24)	101.3 (7.96)	101.1 (8.30)	101.1 (8.10)	101.1 (8.36)
41	103.4 (10.18)	103.2 (8.23)	103.1 (9.01)	103.2 (8.61)	103.2 (9.03)
42	103.0 (8.36)	102.6 (7.14)	102.7 (7.50)	102.7 (7.30)	102.8 (7.55)
Total	93.2 (15.95)	94.1 (13.90)	93.9 (14.41)	94.0 (14.15)	93.9 (14.52)

GA: gestational age in weeks; BSA: body surface area

measurement using these formulas. In addition, in order to develop a clinically feasible BSA scale, length was transformed into weight with the assumption of the square root relation between the two, and a logarithm equation for BSA measurement was fabricated using only weight. Figure 4 illustrates the scale for BSA measurements using only weight (400–7000 g), which could be implemented as a bedside use for high-risk infants.

Discussion and Conclusion

Although estimating the BSA of high-risk infants is of significant interest to health professionals especially considering its applications in therapeutic regimens, there is a paucity of proper methods for these fragile high-risk populations. This study developed a BSA formula (Neo-BSA) that can be used for all infants, including ex-

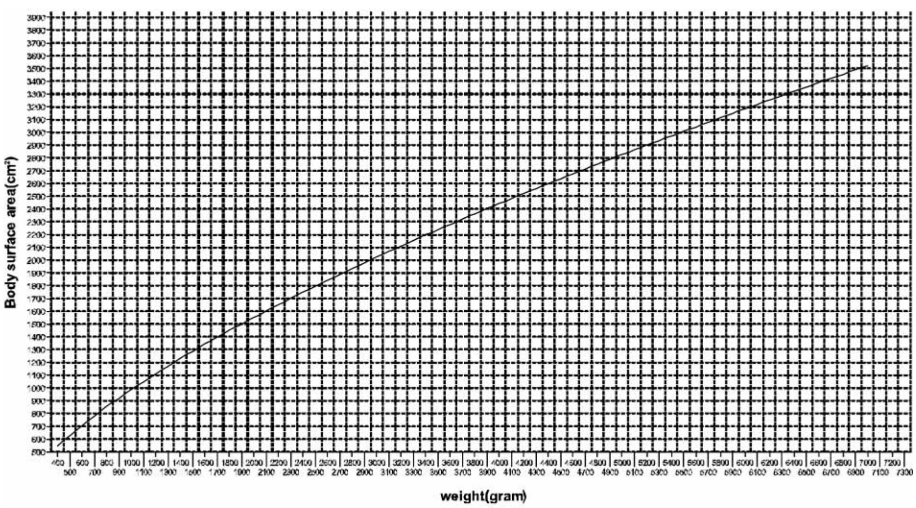

Fig. 4. BSA scale using weight only for infants.

TABLE 4
VARIATION IN PERCENTILE OF BSA MEASUREMENTS COMPARED TO MEAN-BSA

GA	Boyd variation	Dubois variation	Meban variation	Mosteller variation	F (p)
	$\overline{X}$ (SD)	$\overline{X}$ (SD)	$\overline{X}$ (SD)	$\overline{X}$ (SD)	
24	–3.0 (1.13)	–1.4 (0.76)	1.9 (0.17)	–2.4 (0.35)	68.1667 (.000)
25	–3.7 (2.79)	–0.5 (1.98)	1.5 (0.49)	–2.6 (0.86)	26.2317 (.000)
26	–1.9 (4.71)	–1.8 (3.94)	1.6 (0.99)	–2.0 (1.40)	3.0886 (.039)
27	–1.4 (2.10)	–1.9 (1.63)	1.4 (0.45)	–1.9 (0.64)	29.8021 (.000)
28	–1.1 (2.62)	–1.9 (2.02)	1.2 (0.42)	–1.7 (0.81)	18.8141 (.000)
29	–0.1 (3.71)	–2.5 (2.60)	1.1 (0.41)	–1.4 (1.18)	9.6181 (.000)
30	–0.2 (2.05)	–2.4 (1.55)	1.1 (0.40)	–1.5 (0.63)	50.3366 (.000)
31	0.9 (2.38)	–2.9 (1.74)	0.9 (0.33)	–1.1 (0.75)	56.4372 (.000)
32	0.6 (2.05)	–2.6 (1.60)	0.8 (0.35)	–1.2 (0.63)	65.9024 (.000)
33	0.9 (2.36)	–2.6 (1.74)	0.7 (0.29)	–1.1 (0.73)	79.3982 (.000)
34	2.5 (1.98)	–3.7 (1.53)	0.6 (0.29)	–0.6 (0.62)	384.9441 (.000)
35	2.8 (2.11)	–3.9 (1.51)	0.6 (0.23)	–0.5 (0.67)	582.3440 (.000)
36	3.2 (1.79)	–4.0 (1.33)	0.5 (0.23)	–0.3 (0.57)	1884.137 (.000)
37	3.9 (1.83)	–4.4 (1.34)	0.4 (0.20)	–0.1 (0.59)	4796.08 (.000)
38	4.6 (1.69)	–4.9 (1.25)	0.4 (0.19)	0.1 (0.54)	13015.12 (.000)
39	4.8 (1.63)	–5.0 (1.23)	0.3 (0.17)	0.2 (0.52)	16121.91 (.000)
40	4.8 (1.63)	–4.9 (1.24)	0.3 (0.19)	0.2 (0.52)	13392.09 (.000)
41	4.9 (1.80)	–4.9 (1.35)	0.3 (0.17)	0.2 (0.58)	4163.54 (.000)
42	5.1 (1.35)	–5.1 (1.01)	0.3 (0.15)	0.3 (0.43)	386.94 (.000)
Total	4.2 (2.20)	–4.6 (1.49)	0.4 (0.28)	–0.0 (0.71)	32681.23 (.000)

Variation in %; BSA in cm^2
GA; gestational age; BSA: body surface area

tremely LBW newborns. Also, a BSA scale was constructed that used only body weight, as length measurements are often not feasible in most neonatal practices.

Neo-BSA revealed near-perfect correlations with Meban-BSA and Mosteller-BSA, by showing a maximum 2.6% of variance, which decreased as GA increased (Figure 1). A high correlation was still observed with Boyd-BSA and Dubois-BSA, which are popular surface area estimates for the general population. However, since a correlation implies a similarity of pattern between two parameters, a high correlation among BSA measurements in this study is not unexpected, considering that Neo-BSA was constructed from these four formulas. In other words, regardless of a good correlation between two measures, a systematic error could still exist, evidenced by Euclidian distance (Table 5), which may be useful to compare the suitability of Neo-BSA with the other formulas. In this study, the Euclidian distance was shortest between Neo-BSA and Meban-BSA (601.1), followed by Mosteller-BSA. The near-perfect correlation and the smallest Euclidian distance between Neo-BSA and Meban-BSA supports the overall validity as Neo-BSA as the best body surface estimate. This is consistent with the previous report that found that Meban-BSA provides the best surface estimates by showing the least variance (<3%) among several BSA measurements in full term infants[11].

Meban (1983)[14] measured the BSA of fetuses or stillborns ranging from 8–4080 g by directly covering skin with aluminum foil or using skin dissection methods in some fetuses[14]. Regardless of the small sample size and little information on the characteristics of the samples, the findings of that study were similar to the evaluation of the suitability of Neo-BSA in this report since the two measurements were derived from similar subjects. Neo-BSA was developed from 5014 high-risk newborns, rep-

TABLE 5
SIMILARITY AND DISSIMILARITY OF THE DEVELOPED NEO-BSA FORMULA TO OTHER FORMULAS

		Boyd-BSA	Dubois-BSA	Meban-BSA	Mosteller-BSA
Neo-BSA	Correlation coefficient (p)	.996 (.000)	.996 (.000)	1 (.000)	1 (.000)
	Euclidean distance	7066.0	7120.5	601.1	892.8

* p<.001

resenting almost the entire spectrum of newborns in terms of birth weight and GA, of which some would share comparable characteristics to those in the Meban (1983) study. Therefore, it is likely that Neo-BSA and Meban-BSA mutually support the validity of each formula. In particular, the validity of Neo-BSA compared to Meban-BSA is actually and theoretically acceptable, since direct BSA measurement, laboratory wrapping or coating techniques are no longer regarded as feasible and applicable to infants.

Mosteller-BSA was found to be almost as good as Meban-BSA, with a slightly larger Euclidian distance (892.8), compared to Mean-BSA. Although the Mosteller formula has provided very accurate estimates in healthy newborns from Saudi Arabia[18] and Korea[11], special precautions are warranted when applying the Mosteller formula to high-risk infants such as LBW infants, considering that the two studies just cited were performed on healthy newborns with a mean weight of 2900–3254 g. In particular, the Mosteller-BSA may overestimate the BSA for individuals with a shorter body and bulkier limbs, such as obese subjects[19,20] and similar to newborns. Therefore, general use of Mosteller-BSA is not appropriate, pending more validation, regardless of its practical merits of simplicity and ease of calculation for high-risk infants.

On the other hand, the Boyd-BSA and Dubois-BSA revealed substantial variations regardless of similarity of patterns to Neo-BSA as evidenced by a high correlation (r=.996) and large Euclidian distance (7066.022 and 7120.451) in BSA measurements of high-risk infants. An interesting finding was observed in Boyd-BSA, where the direction of variance was reversed at about 30 weeks GA, resulting in an underestimation of BSA before 20–30 weeks GA, in contrast to overestimating BSA after 31 weeks GA. Overestimation of BSA by 5–12% has been reported using the Boyd-BSA, where most subjects were healthy newborns[11,21]. However, while little is reported on BSA measurements in preterm births, this study identified the underestimation of BSA by Boyd-BSA for žsmall preterm' babies born before 29 weeks GA. It demonstrated the largest variance of Boyd-BSA to Neo-BSA (Figure 1). A comparable finding was identified in 2336 Korean school-age children in grades 4–6, in which the Boyd-BSA produced the lowest BSA for thin children and the highest BSA measurement for obese children among the three BSA measurements, Boyd-BSA, Dubois-BSA and Mosteller-BSA[22]. Considering the quite large sample sizes in this and the above studies, the Boyd-BSA seems to underestimate BSA for light and heavy subjects in pediatric populations.

This phenomenon can be explained by the fact that Boyd-BSA uses weight only. Since weight is the major determinant of BSA rather than height, more variance in BSA measurement could be calculated when variance comes from weight. The overestimation or underestimation by Boyd-BSA by the weight of infants may be explained by the mathematical function of the formula itself using weight only. Therefore, caution is necessary in using Boyd-BSA for infants, whether large or small in size. For Boyd-BSA, having a higher surface-to-mass ratio with relatively less importance of length may be acceptable in neonatal practice where height measurement may not be available in high-risk infants.

Finally, Dubois-BSA demonstrated a maximum 5% underestimation of BSA against Neo-BSA. The degree of underestimation became greater as GA increased. Similar findings of BSA underestimations of 5–9% have been reported in healthy newborns[11,2,23] and 3–5% underestimation in obese adults[17]. However, constant reports in underestimation of Dubois-BSA including the present finding, suggests the existence of systemic error in applying the Dubois formula to modern subjects, which was developed from only nine individuals including just one child almost one century ago[13].

In the present study, the widest variance, about 10% of the maximum deviation against the Mean- BSA, was observed using Boyd-BSA and Dubois-BSA. The Boyd formula using only weight has been acknowledged for pediatric use, with modified guidelines for infants[24]. Measurement of length may not be possible in every pediatric instance[5]. The Dubois formula is popular as it is the basis for the currently available BSA nomogram. However, the present study's findings raise a substantial concern about applying these two formulas for high-risk infants.

In conclusion, this present study developed the Neo-BSA as a formula for high-risk infants, especially for those in the 400–7000 g weight category. The Neo-BSA formula has the clinical advantage of using only weight (even though not as refined), considering that length as a measurement is not usually feasible due to the high-risk newborn's body posture. This BSA scale identifies BSA measurements based on weight only (Figure 4), so it can be easily and quickly applied in clinical practice to high-risk infants. Neo-BSA may be the most suitable formula for BSA measurement in high-risk infants in our modern society, with new emerging advances in health sciences and reproductive technologies that increase survival of high-risk infant populations. Recent study supported a developmental and clinical significance of investigation on various physical parameters of these populations at a very early stage of postnatal age[25]. Further studies are required to confirm our findings with various populations and ethnic groups globally and under various clinical conditions, particularly considering that physical parameters such as weight, height, and BSA at birth can lead to further understanding on intrauterine growth variation in relation to genetic and/or environmental interactions.

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FORMULA I SKALA ZA PROCJENU TJELESNE POVRŠINE KOD VISOKORIZIČNE DJECE

SAŽETAK

Napredovanja u medicinskoj tehnologiji i zdravstvenim znanostima dovela su do rapidnog povećanja u prevalenciji i morbiditetu visokorizične djece s kroničnim ili stalnim posljedicama, kao što je preuranjeno rođenje dijeteta. Potrebna je odgovarajuća formula za procjenu visokorizične djece preko tjelesne površine (BSA) kako bi se točnije odredili terapeutski režimi u kliničkoj praksi. Provedena je studija kohorte koja je uključivala 5014 visokorizične djece kako bi se razvila odgovarajuća formula za procjenu pomoću BSA, koristeći četiri postojeće BSA jednadžbe u literaturi. BSA kod visokorizične djece izračunata je koristeći četiri BSA jednadžbe (Boyd-BSA, Budois-BSA, Meban-BSA, Mosteller-BSA), nakon koje je nova računica, Mean-BSA, aritmetički izvučena kao referenca BSA mjere. Koristila se multipla regresija, uz pomoć nelinearne krivulje najmanjeg kvadrata s obzirom na trend linije i nove jednadžbe, koristeći Neo-BSA koji je razvijem uz pomoć programa Excell i SPSS 17.0. Neo-BSA jednadžba konstruirana je ovako: Neo-BSA=$5,520 x W^{0,5526} \times L^{0,3800}$. Uz pretpostavku odnosa korijena najmanjeg kvadrata između težine i duljine, BSA skala, koja koristi samo težinu, proizvedena je specifično za kliničku upotrebu, gdje je težina dostupnija u visokorizičnim dječjim populacijama nego duljina. Valjanost Neo-BSA procijenjena je naspram Meban-BSA, najboljom od četiri jednadžbe visokorizične djece, budući da postoji sličnost proučavanih subjekata u ove dvije studije. Ostale formule otkrile su bitne varijance u BSA, u usporedbi s Neo-BSA. Ovo istraživanje je razvilo novu jednadžbu tjelesne površine, Neo-BSA, kao najbolje odgovarajuću formulu za mjerenje visokorizične djece u suvremenim društvima, gdje se brzorastućoj populaciji novorođenčadi sa skraćenim gastacijskim periodom povećava prevalencija kao rezultat novih dostignuća u zdravstvenim znanostima i novim razvojima reproduktivne tehnologije. Specifično, skala od 400–7000 g tjelesne težine beba, koja je proizašla iz Neo-BSA jednadžbe, ima kliničku prednost koristiti samo težinu kao mjeru, budući da duljina često nije informativna kao mjera zbog tjelesne postave novorođenčeta. Daljnje studije trebale bi potvrditi naše rezultate za korištenjem Neo-BSA i BSA skale (temeljene na težini) za različite populacije i etnicitete uslijed različitih kliničkih uvjeta.