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Six commonly used empirical body surface area formulas disagreed in young children undergoing corrective heart surgery

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Abstract

Aim: Formulas for empirical body surface area (BSA), which is used to estimate body size and standardise physiological parameters, may disagree in children. We compared six commonly used BSA formulas—Du Bois, Boyd, Costeff, Haycock, Meban and Mosteller—in a surgical cohort.

Methods: This retrospective single-centre cohort study comprised 68 children who had corrective heart surgery at Skåne University Children's Hospital, Lund, Sweden, from February 2010 to March 2017.

Results: The children (51% female) underwent surgery at a mean weight of 7.0 kilograms (range 2.7-14.1 kg) and a mean age 11 months (range 0-43 months). All the BSA formulas showed good correlation with mean BSA, but there were considerable variations between them. Mosteller's formula was exactly the same as the mean BSA (bias 0.000). The Du Bois and Boyd formulas had the largest mean BSA deviations (bias −0.012 and 0.015). Costeff's formula showed good agreement with mean BSA, Haycock's formula showed minimal overestimation and Meban's formula demonstrated a systemic error in older children.

Conclusion: Commonly used BSA formulas did not agree in young children undergoing heart surgery, but they were all close to the overall mean of the six formulas, with the Mosteller formula producing the same value.

KEYWORDS
body surface area estimation, clinical treatment, empirical formulas, heart surgery, young children

1 | INTRODUCTION

Body surface area (BSA) has been used to estimate body size and standardise physiological parameters since the beginning of the 20th century.[1,2] It is vital in determining the dosage of multiple medical treatments, as well as evaluating clinical parameters, such as cardiac function and renal clearance.[3] Direct gold standard measurements of BSA, such as geometric, body moulding and three-dimension scanning methods, are often impractical, expensive and time-consuming. Therefore, a number of empirical BSA formulas have been

Abbreviations: BSA, body surface area.

developed in the last 100 years to simplify its estimation. Today, there are more than 25 different BSA formulas available. Some have been designed for patient groups with specific medical conditions, but most seem to be inaccurate in particular groups, such as young children and overweight patients.[3-5] Falsely estimating BSA can have negative consequences, as it has been suggested that up to 30% of patients might receive inadequate treatment due to these inaccurate calculations.[6] BSA estimates are used on a daily basis in paediatric medicine, but few BSA formulas have ever been validated in children and there has been limited research carried out on young children with congenital heart defects.[3,7,8]

The aim of this study was to compare the BSA estimates obtained using six different formulas in young children undergoing corrective heart surgery. We hypothesised that there would be no difference in the calculations in this cohort.

Key notes

- We compared six different, empirical body surface area (BSA) formulas in a Swedish surgical paediatric cohort.
- This retrospective single-centre cohort study comprised 68 children who underwent corrective heart surgery at a mean weight of 7.0 kilograms and a mean age 11 months.
- Although the BSA formulas did not agree with each other, they were fairly close to the overall mean value and the Mosteller formula was the same.

2 | PATIENTS AND METHODS

2.1 | Study population

This was a single-centre retrospective comparison study that comprised children under 15 kg that had undergone corrective heart surgery. The weight and height of all the children had been measured before surgery, as part of the preoperative admission examination. All the children in this study had previously been included in separate prospective cardiac output comparison studies at Lund Children's Hospital, Sweden.[9,10] These studies had all been approved and registered by the Ethics Committee of Lund University, Sweden, and parental consent had been provided.

2.2 | Body surface area formulas

Empirical BSA formulas are used to estimate BSA, as it is often unknown, but it is impossible to define the true accuracy of different formulas. However, it is possible to compare different formulas to see how well they agree with each other.

We chose six of the most commonly used BSA formulas for this study and focused on those that were simple to use or had been developed as a result of paediatric studies (Table 1). The Du Bois formula, which was first presented in 1916, has remained the most widely used BSA formula in clinical medicine.[2] However, it was only based on a small sample of nine heterogenous subjects, including an obese elderly female, a deformed child and an adult midget and important limitations have been reported.[11,12] The original Boyd formula was developed from a large sample of children in 1935, and both their weight and height were used. The formula was later simplified, so that just weight was needed and it remains the most commonly used BSA formula when a child's weight is the single determining factor.[13,14] The Costeff formula was developed in 1966 to be used in children and, like the Boyd formula, it only uses weight as the determining factor for BSA. It never achieved general popularity and was almost forgotten until recently.[15-17] The Haycock formula was developed in 1978 using the geometric method and has performed well in children.[18] The Meban formula was developed from foetal research in 1983 and was used to estimate BSA in newborn infants. It has been shown to be very accurate in that age group.[7,19,20] The Mosteller formula, which was first presented in 1987, is a simplified version of an earlier formula that was developed by Gehan and George and it has been reported to be promising in paediatric patients.[21-25]

As the true BSA was unknown in this study, we calculated the mean BSA by combining the estimates obtained from the six formulas described above and used that as a surrogate measurement. We felt that this method provided the most accurate BSA estimate for comparison purposes. For a specific formula to perform sufficiently in comparison with the mean BSA, its mean value had to be as near to the mean BSA value as possible, with the least bias. This had to be within the 95% limits of agreement and provide a percentage range deviation of $< \pm 5\%$.

2.3 | Statistical analysis

The data were recorded in Windows Excel Office 365 (Microsoft Corporation) and analysed using Statistica version 13 (Dell Inc).

A priori statistical power analysis was performed for the sample size estimation based on data from an earlier study by Orimadegun and Omisanjo, which compared different BSA calculations in children.[24] The bias in that study was 0.02 m^2, with a standard deviation of 0.05 m^2, resulting in an effect size of 0.40. This was based on comparing the Boyd formula to the mean BSA value in 1-year-old children. We estimated that a sample size of at least 55 subjects was needed to detect a BSA difference between the formulas. This was calculated using G-Power 3.1.9.2 software (Kiel University, Schleswig-Holstein, Germany), with a paired one-tailed *t* test for the difference of means, an alpha error value of 0.05 and a power value of 0.90. The number of subjects in this study was related to the number of patients available from ongoing cardiac output comparison studies at the study site, Lund Children's Hospital.[9,10,26]

TABLE 1 The six empirical BSA formulas used in this study

Formula	Equation	Subjects
Du Bois (1916)	$\text{BSA} = 0.007184 \times \text{weight (kg)}^{0.425} \times \text{height (cm)}^{0.725}$	All ages (n = 9)
Boyd (1935)*	$\text{BSA} = 4.688 \times \text{weight (kg)}^{(0.8168 - 0.0154 \times \text{logweight (kg)})}$	Children (n = 401)
Costeff (1966)	$\text{BSA} = (4 \times \text{weight (kg)}) + 7) / (90 + \text{weight (kg)})$	All ages (n = 220)
Haycock (1978)	$\text{BSA} = 0.024265 \times \text{weight (kg)}^{0.5378} \times \text{height (cm)}^{0.3964}$	All ages (n = 81)
Meban (1983)	$\text{BSA} = 6.4954 \times \text{weight (g)}^{0.562} \times \text{height (cm)}^{0.320}$	Human foetuses (n = 79)
Mosteller (1987)	$\text{BSA} = \sqrt{(\text{weight (kg)} \times \text{height (cm)} / 3600)}$	Adults (n = unknown)

Abbreviations: BSA, body surface area; n, number of subject; year, year presented.

*This study used the simplified Boyd formula that is just based on weight. The original formula published in 1935 also used height.

Although a BSA to two decimal places is currently used in clinical practice, we have presented the mean BSA results to three decimal places, to highlight the exact difference between the BSA formulas. The results are presented as means and standard deviations, unless otherwise stated.

The correlation coefficient (*r*) and the root mean square error were obtained from the regression analyses of the BSA values of each of the six formulas, when they were compared with the mean BSA. The root mean square error calculates the difference between measured and predicted data, namely the mean BSA, in the absence of a gold standard for BSA. This makes it possible to estimate accuracy of any empirical formula. A lower root mean square error value indicates better concordance with the predicted value.[27]

The Bland-Altman analysis was used to see whether there were significant differences between the six different BSA formulas and the mean BSA[28] and the results were then plotted.

The Shapiro-Wilk test for normality was used to confirm the normal distribution of the difference between mean BSA from the individual formulas and mean BSA value that was calculated from all six BSA formulas.

The 95% limits of agreement analysis was carried out to determine whether the formulas agreed sufficiently with each other, so that they could replace each other. The limits of agreements were calculated as a mean bias of ±1.96 multiplied by the standard deviation (SD) of the bias.

The percentage deviation of each of the six formulas in relation to the mean BSA was identified by calculating the mean difference between the different formulas, for example: (BSA by Du Bois formula–mean BSA)/mean BSA × 100%.

3 | RESULTS

Between 9 February 2010 and 9 March 2017, 68 children were enrolled for haemodynamic studies at Lund Children's Hospital and they were all included in this retrospective study. The children's mean weight was 7.0 ± 30 kg (range 2.7-14.1 kg), their mean height was 67.9 ± 12.6 cm (range 47.0-94.0cm) and their mean age was 11 ± 11.3 months (range 0 to 43 months; Table 2).

3.1 | Correlation between the different BSA formulas

All the BSA formulas showed good correlation with the mean BSA, with a correlation coefficient range from 0.998 to 1.000 ($P < .001$). The Mosteller formula had the lowest root mean square error of all the six formulas when compared with mean BSA, which indicated that it was closest to the predicted BSA value. The Boyd formula had the largest root mean square error, closely followed by the Du Bois formula, which meant that these two formulas had the lowest agreement with the predicted BSA value. They also accounted for 17% of the variations from the overall mean (Table 3).

3.2 | Agreement between different BSA formulas

The mean BSA of all six formulas was 0.360 ± 0.111 m^2, which was exactly the same mean BSA as the Mosteller formula. The mean BSA estimates calculated by all six formulas are presented in Table 4, and Figure 1 shows the Bland-Altman graphs showing bias and limits of agreement. We were very concerned to see that the limits of agreements for the Du Bois, Boyd and Haycock formulas did not include the mean BSA value, which indicated a considerable disagreement in BSA estimation. The differences between the mean BSA and the different formulas were normally distributed by histograms and Shapiro-Wilk test for normality for all formulas, apart from Meban's formula (Figure 1). That was the only formula to show a clear systemic error, according to the Bland-Altman graph, resulting in an underestimation of BSA in older children.

The mean percentage deviation of the six different BSA formulas from the mean BSA was largest for Boyd's formula, while Mosteller's formula was the smallest, as shown in Figure 2. Boyd's and Haycock's formulas overestimated BSA, by a mean percentage deviation of 4.5% (range 1.0%-8.1%) and 1.0% (range 0.2%-1.9%), respectively. The other four formulas underestimated BSA: Du Bois had a percentage deviation of −3.5% (range −7.7%-0.5%), Costeff's formula was −1.2% (range −4.9%-1.6%), Meban's was −0.5% (range −1.7%-0%) and Mosteller's was −0.1% (range −1.8%-1.7%). The mean percentage BSA difference between the two

TABLE 2 The weight, height, age and body surface area estimates of the 68 study subjects with different formulas

Weight (kg)	Height (cm)	Age (months)	Du Bois (m^2)	Boyd (m^2)	Costeff (m^2)	Haycock (m^2)	Meban (m^2)	Mosteller (m^2)	Overall mean (m^2)
4.7	58.0	1	0.263	0.290	0.272	0.279	0.276	0.275	0.276
7.5	71.0	15	0.372	0.403	0.379	0.389	0.383	0.385	0.385
2.7	47.0	2	0.179	0.196	0.192	0.190	0.189	0.188	0.189
10.0	77.0	23	0.446	0.492	0.470	0.468	0.462	0.462	0.467
5.6	64.0	4	0.305	0.328	0.308	0.319	0.314	0.316	0.315
12.9	91.5	33	0.563	0.587	0.569	0.575	0.563	0.573	0.572
5.5	64.0	3	0.303	0.325	0.305	0.317	0.312	0.314	0.313
2.9	51.5	1	0.197	0.206	0.200	0.205	0.202	0.204	0.202
13.6	94.0	28	0.587	0.608	0.593	0.598	0.585	0.596	0.594
5.2	61.0	2	0.286	0.313	0.294	0.302	0.298	0.298	0.298
5.9	65.0	7	0.315	0.340	0.319	0.330	0.325	0.326	0.326
4.7	57.0	3	0.260	0.290	0.272	0.277	0.274	0.273	0.274
4.0	56.0	2	0.240	0.259	0.245	0.252	0.249	0.249	0.249
9.2	77.0	24	0.430	0.464	0.442	0.448	0.440	0.444	0.445
5.5	65.0	5	0.306	0.324	0.304	0.318	0.312	0.315	0.313
10.5	83.0	5	0.481	0.509	0.488	0.495	0.486	0.492	0.492
4.2	56.0	3	0.245	0.268	0.253	0.259	0.256	0.256	0.256
11.5	83.0	39	0.499	0.542	0.522	0.520	0.511	0.515	0.518
7.2	70.0	11	0.362	0.391	0.368	0.378	0.372	0.374	0.374
8,7	78.5	23	0.426	0.446	0.424	0.438	0.430	0.436	0.433
7.4	68.0	6	0.357	0.397	0.374	0.378	0.373	0.373	0.375
7.0	65.0	8	0.339	0.384	0.361	0.362	0.358	0.356	0.360
11.6	92.5	26	0.542	0.545	0.526	0.546	0.532	0.546	0.539
13.1	92.5	43	0.571	0.593	0.576	0.582	0.570	0.580	0.579
6.1	65.0	6	0.320	0.348	0.327	0.336	0.331	0.332	0.332
4.2	56.0	2	0.245	0.268	0.253	0.259	0.256	0.256	0.256
5.6	62.0	4	0.298	0.328	0.308	0.315	0.311	0.311	0.312
10.4	81.0	22	0.470	0.505	0.484	0.488	0.480	0.484	0.485
12.6	93.0	36	0.564	0.577	0.559	0.572	0.558	0.571	0.567
5.8	61.0	2	0.299	0.336	0.315	0.319	0.315	0.313	0.316
5.5	59.0	2	0.285	0.324	0.304	0.306	0.303	0.300	0.304
4.4	59.0	3	0.259	0.277	0.261	0.271	0.267	0.269	0.267
9.4	82.0	23	0.454	0.471	0.449	0.464	0.455	0.463	0.459
5.4	64.0	4	0.300	0.320	0.300	0.312	0.308	0.310	0.308
11.0	85.0	23	0.499	0.525	0.505	0.513	0.503	0.510	0.509
8.3	72.0	11	0.392	0.432	0.409	0.413	0.407	0.407	0.410
4.0	55.0	4	0.237	0.259	0.245	0.250	0.248	0.247	0.248
6.1	62.5	5	0.311	0.348	0.327	0.331	0.327	0.325	0.328
6.4	71.0	22	0.348	0.360	0.338	0.357	0.350	0.355	0.351
5.1	67.0	4	0.303	0.307	0.288	0.309	0.302	0.308	0.303
4.2	58.0	9	0.251	0.268	0.253	0.263	0.259	0.260	0.259
7.0	71.0	9	0.361	0.384	0.361	0.374	0.368	0.372	0.370
9.2	80.0	19	0.442	0.464	0.442	0.455	0.446	0.452	0.450
4.5	59.0	4	0.262	0.281	0.265	0.274	0.271	0.272	0.271

(Continues)

TABLE 2 (Continued)

Weight (kg)	Height (cm)	Age (months)	Du Bois (m^2)	Boyd (m^2)	Costeff (m^2)	Haycock (m^2)	Meban (m^2)	Mosteller (m^2)	Overall mean (m^2)
7.9	74.0	9	0.392	0.417	0.394	0.406	0.399	0.403	0.402
10.6	86.0	26	0.495	0.512	0.491	0.505	0.494	0.503	0.500
5.2	60.0	5	0.282	0.312	0.292	0.298	0.295	0.294	0.296
3.2	51.0	4	0.204	0.221	0.212	0.216	0.213	0.213	0.213
7.6	76.0	14	0.393	0.406	0.383	0.402	0.394	0.401	0.397
4.0	55.0	1	0.237	0.259	0.245	0.252	0.248	0.247	0.248
14.1	93.0	41	0.591	0.624	0.609	0.607	0.595	0.604	0.605
5.7	64.0	5	0.307	0.332	0.311	0.322	0.317	0.318	0.318
4.7	59.0	2	0.267	0.290	0.272	0.281	0.277	0.278	0.277
4.6	59.0	6	0.264	0.286	0.268	0.278	0.274	0.275	0.274
10.8	79.0	19	0.469	0.519	0.498	0.493	0.486	0.487	0.492
4.1	55.0	5	0.239	0.264	0.249	0.254	0.251	0.250	0.251
5.5	61.0	4	0.292	0.324	0.304	0.310	0.306	0.305	0.307
4.3	52.0	0	0.234	0.273	0.257	0.255	0.253	0.249	0.253
4.8	61.5	3	0.277	0.295	0.276	0.289	0.284	0.286	0.285
5.1	55.0	2	0.262	0.307	0.288	0.285	0.284	0.279	0.284
9.2	81.0	28	0.446	0.464	0.442	0.457	0.448	0.455	0.452
3.8	53.0	2	0.225	0.250	0.237	0.240	0.238	0.237	0.238
9.8	79.0	16	0.450	0.485	0.463	0.468	0.460	0.464	0.465
11.8	84.0	20	0.509	0.552	0.532	0.530	0.521	0.525	0.528
4.5	56.0	5	0.252	0.281	0.265	0.269	0.266	0.265	0.266
7.1	64.0	5	0.337	0.388	0.365	0.362	0.359	0.355	0.361
5.0	61.5	4	0.282	0.303	0.284	0.295	0.291	0.292	0.291
3.1	48.0	0	0.192	0.216	0.208	0.207	0.205	0.203	0.205

Abbreviation: BSA, body surface area.

formulas that disagreed most, Du Bois and Boyd's formula, was 8.2% (range 0.5%-17.2%)

4 | DISCUSSION

This study found that the Mosteller formula provided the most accurate estimate of BSA in young children with congenital heart disease compared with the mean BSA of the six commonly used formulas we studied. Although all the formulas showed good correlation to the overall mean, there were considerable differences between them. It is very important that clinicians understand that BSA formulas do not always agree and that they are aware of possible errors and limitations of their BSA estimates.

The Mosteller formula has only been studied by a handful of papers since it was introduced in 1987.[3,7,22,24,29] It is probably the most simple and accurate formula available, it is easy to use and remember and it can be estimated on a simple calculator with a square root function. Our results confirm that the Mosteller formula performed well in our cohort of young children undergoing heart surgery.

TABLE 3 Correlation between the BSA values obtained by the different formulas and the overall mean BSA (n = 68)

Formula	Correlation (*r*)	R^2	RMSA	*P* value
Du Bois	0.999	.998	0.00153	<.001
Boyd	0.999	.998	0.00191	<.001
Costeff	0.999	.998	0.00084	<.001
Haycock	1.000	1.000	0.00038	<.001
Meban	1.000	1.000	0.00046	<.001
Mosteller	1.000	1.000	0.00021	<.001

Abbreviation: BSA, body surface area; *r*, correlation coefficient; RMSA, root mean square error.

Meban's study is probably the most accurate study on BSA measurements carried out in paediatrics to date.[19] It compared all the available methods for estimating BSA in a cohort of 79 deceased premature foetuses and newborn babies, by using the geometric method. Those results were compared with aluminium foil body moulding and total body surface area measurements of dissected skin in six subjects. Meban's study found that all these methods were in agreement and this study resulted in the

TABLE 4 Comparison of overall mean BSA with estimated BSA mean value for each formula (n = 68)

Formula	Mean	Standard deviation	Bias	Limits of agreement	Coefficient of variation
Du Bois	0.348 m^2	±0.110 m^2	−0.012 m^2	±0.010 m^2	31.7
Boyd	0.375 m^2	±0.112 m^2	0.015 m^2	±0.010 m^2	29.8
Costeff	0.356 m^2	±0.111 m^2	0.004 m^2	±0.009 m^2	30.9
Haycock	0.363 m^2	±0.110 m^2	0.003 m^2	±0.002 m^2	30.3
Meban	0.357 m^2	±0.107 m^2	−0.002 m^2	±0.006 m^2	30.0
Mosteller	0.360 m^2	±0.110 m^2	0.000 m^2	±0.005 m^2	30.7

development of the Meban formula for estimating BSA in newborn infants. A study by Ahn et al[7] confirmed that Meban's formula was very accurate in healthy newborn infants, but stated that the Mosteller formula performed almost as well. As the Meban formula was specifically designed for newborn infants, it was not clear how it would perform in older children. However, our results show that the Meban formula had a systemic error and became more inaccurate with increased weight, while the Mosteller formula remained accurate compared with the mean BSA (Figure 1). One reason for this systematic error might have been differences in body proportions between foetuses and newborn infants compared with older children.

The Haycock formula performed rather well overall, as it demonstrated the least variation of all the formulas, but it did slightly overestimate BSA (0.003 m^2). It was significant that its narrow limits of agreement did not include the mean BSA. Our results confirm the original findings of Haycock et al's 1970s study that the Du Bois formula seems to underestimate BSA in children by about 8% when compared to the Boyd formula.[18]

The Du Bois formula still continues to be the most frequently used formula for paediatric patients, although a number of studies have indicated that it might underestimate BSA in young children. Our results support these previous findings and show that the same applies to young children with congenital heart defects. The Du Bois formula was originally developed from a small group of very heterogenous subjects with a wide range of abnormal body proportions. This fact may partly explain why the Du Bois formula repeatedly underestimates BSA in young children.

The simplified Boyd formula, which only used weight, seemed to overestimate BSA in this study when compared to mean BSA. It is hard to speculate why there was such an overestimation in BSA when the formula was so simple. We also tested Boyd's original formula on our cohort, which also included height, and this also caused a similar overestimation (data not shown). One reason for this might be that Boyd focused on healthy children in her study, while our study involved young children with congenital heart defects. Children with congestive heart failure can also develop liver and kidney failure due to their underlying heart disease. This can, in turn, influence their metabolic capacity with regard to different drugs and treatments. An overestimation of BSA may lead to overtreatment, resulting in possible toxic overdoses, with more side effects and iatrogenic organ failure.

At first glance, the bias presented for the Du Bois and the Boyd formulas in this study does not seem clinically important, as the bias was only −0.012 m^2 and 0.015 m^2, respectively. However, as the limits of agreements for both the formulas did not reach the overall mean for the six BSA formulas, by displaying individual BSA range fluctuations of about 8%, the difference should not be ignored in this age group, which had very small therapeutic margins (Figure 2).

4.1 | Formulas that use just weight and not height

The first BSA formula, which was presented in 1879, was the Meeh formula and this only used weight to estimate BSA. It was then mostly replaced by the original Du Bois formula, which used both weight and height.[1,2] In general, BSA formulas that combine weight and height have been considered to be more accurate, as they provide better BSA estimates in patients with abnormal body proportions. However, in practical terms, BSA formulas that just use weight have performed well and allow BSA to be estimated from a simple weight chart. Our study included two BSA formulas that use just weight, for comparison purposes. These were the simplified Boyd formula and the recently revived Costeff formula. Of the two formulas, Costeff's formula was in agreement with the mean BSA in this study, while Boyd's formula seemed to overestimate BSA. Nomograms and complicated BSA formulas have been shown to produce serious BSA calculation errors, even in experienced hands.[29] As the Costeff formula is very simple, its use could reduce errors in BSA calculations.[15,17]

4.2 | Implications of incorrectly estimating haemodynamic parameters

It is a matter of concern that different BSA formulas do not agree in young children in the field of paediatric intensive care medicine, because BSA is used to index and normalise haemodynamic parameters. Redlarski et al[3] reported that BSA estimates could vary by up to 50%, depending on which formula was used in this age group. As Du Bois is the BSA formula that is normally used for indexing haemodynamic parameters, its underestimation might have clinical consequences. The following theoretical example demonstrates this. A 5 kg child with a cardiac output of 0.90 L/min with a BSA of

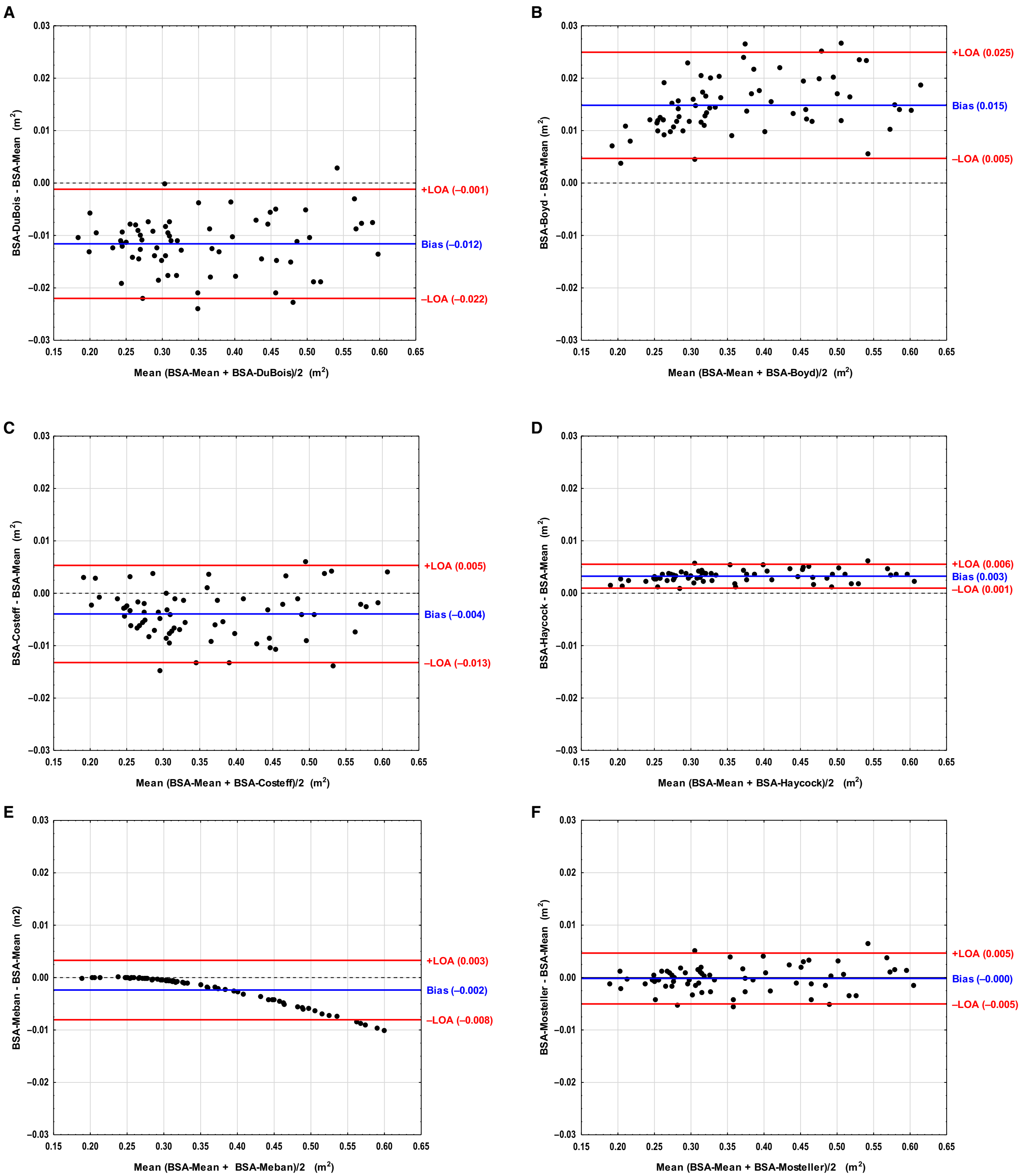

FIGURE 1 Bland Altman analysis comparing different formulas with mean BSA in 68 children weighing under 15 kg Figure showing how the Du Bois formula underestimated BSA (A). Boyd's formula overestimated BSA (B). Costeff's formula, which is only based on weight, performed well (C). Haycock's formula showed little variability, but minimal BSA overestimation (D). Meban's formula was accurate in newborn infants, but due to systematic errors, it became inaccurate for older children (E). Mosteller's formula remained the most accurate of all six formulas throughout the whole group (F)

0.30 m^2 according to the Du Bois formula used in our study would result in a cardiac index of 3.0 L/min/m^2. However, if the BSA was really 0.35 m^2, the actual cardiac index might be about 2.5 L/min/m^2. This false overestimation in cardiac index would wrongly estimate cardiac function and that could influence clinical decisions and cause a delay in supportive treatment.

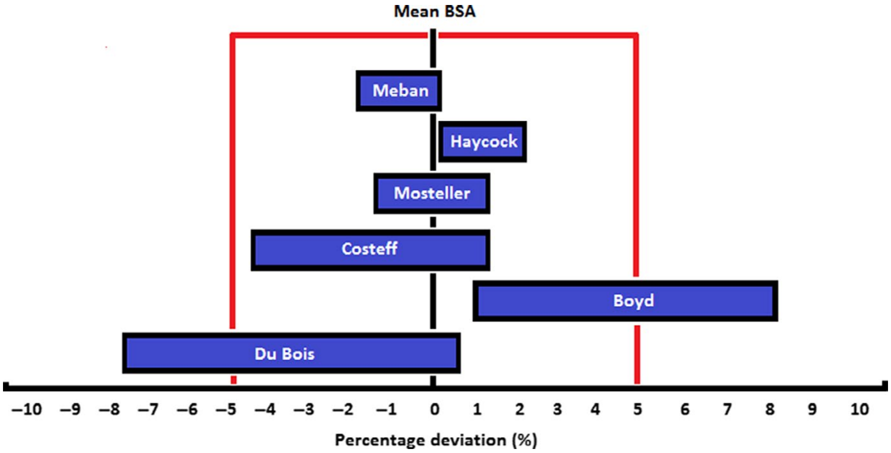

FIGURE 2 Percentage deviation range of different BSA formulas from mean BSA value (red margins mark the ± 5% limits)

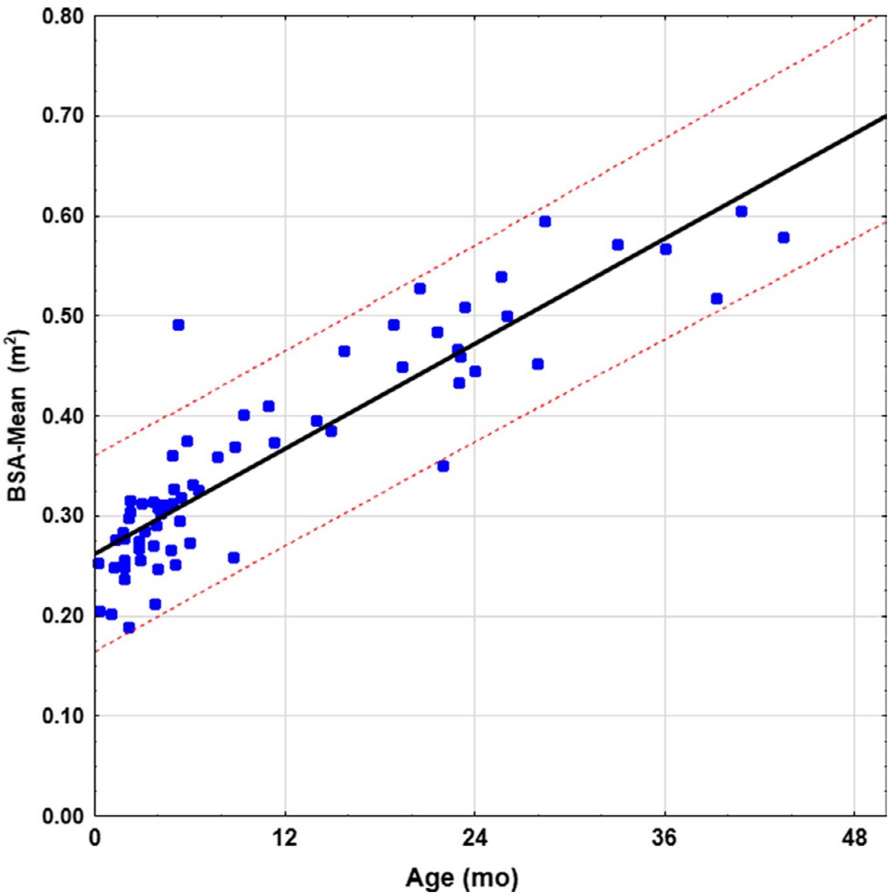

FIGURE 3 Scatterplot of mean body surface area (BSA mean) against age of all 68 patients included in this study. Red line marks predicted 95% confidence interval. The aim of the study was to investigate BSA estimations in children under 15 kg as few studies have compared different BSA formulas in young children. Earlier studies have suggested that empirical BSA formulas start to disagree when BSA was < 0.70 m^2

4.3 | Congenital heart defects and differences in anthropometry

The main limitation of this study was that it focused on a small cohort of patients with congenital heart defects under 15 kg (Figure 3). In general, young children with congenital heart defects tend to lie at the lower margins of the normal growth curve, due to higher energy expenditure and nutritional problems. Their BSA does not represent the general population of healthy children that most BSA nomograms have been based on. However, BSA estimates are most frequently used in sick children, such as malnourished cancer patients or children with heart failure. These children are underrepresented or excluded in larger studies, and this has created inaccurate overall pictures.[23,24,30] The number of patients presented in this study should be sufficient to provide an overall BSA estimates for patients of this age with congenital heart defects. Although anthropometry factors, like race and gender, can influence BSA estimates in the general population, these were not examined in this study. All the BSA formulas compared in this study were developed from European populations that were similar to our patient cohort. Earlier studies have suggested that divisions between the sexes with regards to BSA first become apparent during early adolescence. As magnetic resonance imaging is becoming more available, a study comparing direct BSA three-dimensional scanning with common empirical BSA formulas in this patient group might be of interest in the future.

5 | CONCLUSION

We examined six commonly used BSA formulas and found that they did not agree in young children with congenital heart defects. The Mosteller formula gave the most accurate BSA estimate in these children when it was compared to the mean BSA of the six formulas. The Meban formula was accurate in newborn infants, but underestimated BSA in older children.

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CONFLICTS OF INTEREST

The authors have no conflict of interest to declare.

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