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Comparative Analysis of Different Body Surface Area Estimates among Group of Metal Casting Workers

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***Abstract:** Heat stress evaluations in a particular thermal work environment also requires the need of estimating the metabolic heat generated from a human body. The estimation of this metabolic heat depends on the body surface area (BSA) of the targeted audience employed in that particular work environment. In this study an attempt was made to evaluate the different BSA estimates for a group of 51 metal casting workers. Nine different BSA expressions were evaluated based on the anthropometric variables of casting workers and a comparative analysis among these BSA estimates have been performed. The results concluded slightly considerable mean variations among the different BSA estimates, although strong association (at significance level of 0.01) was observed among the different BSA expressions.*
***Keywords:** Body surface area, anthropometry, workers, metabolic heat, heat stress*

I. INTRODUCTION

Workers employed in hot and humid industrial work conditions (high heat work environments like foundries) are mostly subjected to heavy physical workload, which puts considerable thermal stress on the workers wellbeing. Several work activities like working with hazardous wastes, high heat furnace work operations requires worker to wear personal protective clothing (semipermeable/impermeable), which also contribute significantly to heat stress. Heat stress causes thermophysiological effects on the human body like rise in core body temperature, increased heart rate and excessive sweating. A worker performing intensive physical work in a hot environment builds up body heat, which may be evaluated in terms of metabolic heat (in watts) ([1]-[2]). Metabolic heat (in watts) is evaluated from the metabolic rate by multiplying it with the body surface area (in m2). Figure 1 depicts the metabolic rates for various work activities.

Fig. 1 Different metabolic rates for various work activity types
(Image Courtesy: Sandip Jadhav, CEO, CCTech, 2018, Blog Article: Role of CFD in Evaluating Occupant Thermal Comfort [1])

The heat exchange between the human body and its surrounding environment is a major component of metabolic heat production [2]. The Body surface area (BSA) estimate is valuable for estimating the energy requirements in the heat stress at higher ambient temperatures. Body surface area (BSA) is defined as the calculated surface area of a human body, which provides a better indication of metabolic mass than considering body weight and body mass index, as it is least influenced by abnormal adipose mass. Its application includes evaluating the metabolic heat generated from human body while performing a physical activity (ranging from light to moderate).

It's also beneficial in evaluating cardiac index, (measuring the cardiac output divided by BSA), which gives better estimate for the effective cardiac output and many other clinical investigations. In conducting heat stress studies or thermal comfort study, the evaluation of BSA for the involved subjects yields better estimation of the thermal environment suitability for the targeted audience; which in turns provides better estimation of the heat stress and thermal comfort evaluations. Although there are also few evidence that BSA values are least accurate at certain situations (like extremes of weight, height), where Body Mass Index (BMI) may be a better estimate.

II. METHODOLOGY

In this study an anthropometric survey has been conducted for a group of workers employed in metal casting unit located nearby Chandigarh region in India. The anthropometric variables were used to evaluate the body surface area estimates using different expressions for BSA. A Statistical analysis has been performed using IBM SPSS statistics 26 software package on the anthropometric variables and evaluated BSA estimates.

A. Body Surface area (BSA)

Different mathematical expressions are there that may be used in evaluating BSA (generally expressed in m^2,) without involving direct measurement, utilizing weight (W) in kilograms, and height (H) in centimetres. The most widely used expression nowadays is the Du Bois formula [3]. Other BSA expressions includes Mosteller formula, Haycock, Boyd, and Gehan and George ([4] - [7]), which are also commonly used. The different expression used in this study are described as:

TABLE I

Different expressions for evaluating Body surface area (BSA)

DuBois & DuBois	0.20247 x height (in m)$^{0.725}$ x weight (in kg)$^{0.425}$
Mosteller	0.016667 x height(in cm)$^{0.5}$ x weight(in kg)$^{0.5}$
Haycock	0.024265 x height(in cm)$^{0.3964}$ x weight(in kg)$^{0.5378}$
Boyd	0.0003207 x height (in cm)$^{0.3}$ x weight (in grams)$^{0.7285 - (0.0188 \times \log(weight))}$
Gehan & George	0.0235 x height (in cm)$^{0.42246}$ x weight (in kg)$^{0.51456}$
Shuter & Aslani [8]	0.00949 x weight (in kg)$^{0.441}$ x height (in cm)$^{0.655}$
Fujimoto [9]	0.008883 x weight (in kg)$^{0.444}$ x height (in cm)$^{0.663}$
Schlich [10]	0.000579479 x weight (in kg)$^{0.38}$ x height (in cm)$^{1.24}$
Lipscombe [11]	0.00878108 x weight (in kg)$^{0.434972}$ x height (in cm)$^{0.67844}$

B. Anthropometric Study

An anthropometric study has been performed to collect few anthropometric variables (Stature, weight etc.) of foundry workers useful for the current study. Anthropometric dimensions (stature and weight) of around 51 workers (shown in table 2) have been collected, which were used to calculate the worker's average body surface area using Du-Bois Method and several available BSA expressions. Mean and standard deviation have been calculated for the anthropometric variables as shown in table 3.

III.RESULTS

Statistical analysis was performed using IBM SPSS 26.0 software package. The descriptive analysis results for the two anthropometric variables, BMI and Du-Bois body surface area have been depicted in table 3. The descriptive statistics results for nine different BSA expressions and BMI have been presented in table 4 with slightly considerable mean variations among the different BSA estimates.

Further, Pearson's product moment correlation analysis was performed on the BSA estimates, which have been described in table 5. From the results it may be concluded that strong association was found among the different BSA expressions at a significance level of 0.01. Du-Bois BSA estimate was found to be strongly correlated with Shuter_Aslani, Fujimoto, Lipscombe, Mosteller, and Gehan_George BSA estimates. Although the BMI index was showing a better relationship (correlation coefficient, r = 0.808) with the Boyd BSA expression.

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TABLE III. Measured Anthropometric Dimensions of workers (N = 51)

S.No.	Weight (Kg)	Height (cm)	Height (m)
1.	84.6	174.4	1.744
2.	76.5	173.7	1.737
3.	60.4	170	1.7
4.	66.6	169.2	1.692
5.	87.2	179.4	1.794
6.	73	168.8	1.688
7.	58	170.1	1.701
8.	49.4	163.2	1.632
9.	56.4	177.8	1.778
10.	73.1	168.4	1.684
11.	73.2	166.3	1.663
12.	80.9	176.4	1.764
13.	68.8	167.4	1.674
14.	68.7	170.7	1.707
15.	54.3	168.2	1.682
16.	78.7	171.6	1.716
17.	74.4	169.6	1.696
18.	75.3	169.6	1.696
19.	46.2	162.4	1.624
20.	73.4	173.9	1.739
21.	62.2	177.1	1.771
22.	58.3	160.1	1.601
23.	62.1	153.6	1.536
24.	63.9	170.6	1.706
25.	58.4	165.7	1.657
26.	87	179.7	1.797
27.	92.4	180.2	1.802
28.	66.4	163.3	1.633
29.	79.9	176.6	1.766
30.	71.8	162.9	1.629
31.	67.9	179.4	1.794
32.	81.4	164.2	1.642
33.	85.8	167	1.67
34.	69.8	164.4	1.644
35.	77.1	175.4	1.754
36.	79.3	170.7	1.707
37.	78.3	182.9	1.829
38.	60.9	168.7	1.687
39.	61.3	166.5	1.665
40.	64.1	160.5	1.605
41.	70.6	172.6	1.726
42.	81.5	183.3	1.833
43.	81.9	167.2	1.672
44.	70.8	163.7	1.637
45.	63.8	171.8	1.718
46.	85.9	171.5	1.715
47.	70.8	174.5	1.745
48.	70.6	166.7	1.667
49.	67.8	168.5	1.685
50.	59.7	176.4	1.764
51.	83.3	175.6	1.756

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TABLE IIIII
Mean and standard deviation for Anthropometric variables and Du-Bois Body Surface Area

S.No.	Variables (N=51)	Mean	Standard deviation	Range
1	Weight (Kg)	70.86	10.43	46.2 – 92.4
2	Height (m)	1.7044	0.06233	1.536 – 1.833
3	BMI (Body mass index) (Kg/m2)	24.370	3.185	17.52 – 30.76
4	Du-Bois Body surface area (m2)	1.8188	0.14455	1.467 – 2.124

TABLE IVV
Descriptive statistics results for different BSA expressions (in square metres)

(N=51)	Mean	Std. Deviation	Range	Minimum	Maximum
DU_BOIS	1.8188	.14455	.66	1.47	2.12
Mosteller	1.8275	.15494	.71	1.44	2.15
Haycock	1.8353	.16146	.74	1.43	2.17
Gehan_George	1.8406	.15675	.71	1.45	2.17
Boyd	1.8436	.16086	.73	1.44	2.17
Shuter_Aslani	1.7950	.14357	.65	1.44	2.10
Fujimoto	1.7732	.14294	.65	1.42	2.07
Schlich	1.7093	.14980	.66	1.37	2.03
Lipscombe	1.8260	.14555	.66	1.47	2.13
BMI	24.3703	3.18536	13.25	17.52	30.76

TABLE V
Correlations analysis among various evaluated BSA expressions

(N=51)	DU_BOIS	Mosteller	Haycock	Gehan_G	Boyd	Shuter_A	Fujimoto	Schlich	Lipscombe	BMI
DU_BOIS	1	.994**	.988**	.991**	.982**	1.000**	1.000**	.985**	1.000**	.685**
Mosteller	.994**	1	.999**	1.000**	.997**	.997**	.997**	.960**	.996**	.759**
Haycock	.988**	.999**	1	1.000**	.999**	.993**	.993**	.947**	.991**	.787**
Gehan_G	.991**	1.000**	1.000**	1	.999**	.994**	.994**	.951**	.993**	.778**
Boyd	.982**	.997**	.999**	.999**	1	.988**	.988**	.935**	.986**	.808**
Shuter_A	1.000**	.997**	.993**	.994**	.988**	1	1.000**	.979**	1.000**	.707**
Fujimoto	1.000**	.997**	.993**	.994**	.988**	1.000**	1	.979**	1.000**	.706**
Schlich	.985**	.960**	.947**	.951**	.935**	.979**	.979**	1	.981**	.547**
Lipscombe	1.000**	.996**	.991**	.993**	.986**	1.000**	1.000**	.981**	1	.700**
BMI	.685**	.759**	.787**	.778**	.808**	.707**	.706**	.547**	.700**	1

**. Correlation significant at 0.01 level (2-tailed)

IV. CONCLUSIONS

Body surface area (BSA) provides an effective indication of metabolic mass, which is helpful in evaluating the metabolic heat generated from human body while performing a physical work activity. BSA estimates yields better evaluation of a particular thermal environment suitability for the targeted audience; which are helpful in conducting thermal comfort/ heat stress studies. The current study intended to perform a comparative analysis for nine different BSA estimates among 51 metal casting workers. The results concluded that there were slight variation among the calculated body surface areas (in m^2), whereas strong association was observed between with the different BSA estimates at significance level of 0.01. These BSA estimates may provide better indication of the metabolic heat generated from the subjects involved in high workload activities, which are in turn beneficial for conducting the heat stress evaluations in the particular high heat work environment, like metal casting industries.

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