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THE RELATION BETWEEN CARDIAC OUTPUT AND BODY SIZE*

BY

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A prerequisite in the study of abnormal body function is the ability to establish the limits of normal. In the case of parameters such as cardiac output that vary with the size of the subject, it has become an accepted practice to standardize values in relation to the body surface area. Thus the cardiac index describes the cardiac output per square metre of body surface area, and the stroke index describes the volume of blood per heart beat per square metre of body surface area. The validity of these expressions depends on the premise that there is a constant or straight line relation between body surface area on the one hand, and cardiac output and stroke volume on the other, over the whole range of body size to be studied, and that the relation can be described by a simple regression equation cutting the intercept at zero. Only where this is so is it meaningful to refer to "the normal" cardiac index or stroke index. Though this premise is backed by observations in the case of adult or adolescent subjects, it was until recently entirely unsupported in the case of children and is still unsupported by any data for infants. This report is an attempt to supply the necessary data.

SUBJECTS AND METHODS

The study concerns 77 subjects divided into three age-groups, one consisting of 22 children 3 weeks to 4 years in age, one of 31 children 5 to 15 years of age, and the third of 24 healthy adult volunteers ranging between 20 and 52 years of age. The two younger groups consisted of children without cardiovascular abnormality, in whom minor elective surgery was about to be performed. Physical data regarding 46 of these subjects have been reported elsewhere (Jegier *et al.*, 1961). Light anæsthesia was used in the two younger age-groups. This was induced without premedication with 80 per cent nitrous oxide in oxygen and was maintained with 50 per cent nitrous oxide, in some cases with the addition of 0·25 per cent halothane. The adult group received no sedation but the subjects were rested for half an hour before the procedure. The local pain of venepuncture was minimized by infiltrating the area with 2 per cent "novocaine." These subjects were thus not truly basal and, in an attempt to eliminate the most tense, data were arbitrarily rejected when heart rates exceeded 84 beats a minute.

The cardiac output was calculated from dye dilution curves (Hamilton *et al.*, 1928) using a directly calibrated ear oximeter. Injections were made into an antecubital vein, or in the case of young children into the external jugular vein, and were immediately and forcefully flushed in with 5–10 ml. normal saline, a technique that gives identical results to injections made into the central circulation (Bousvaros *et al.*, 1962). In earlier studies the indicator was Evans blue dye (T 1824) in a dose of 0·2–0·3 mg./kg., the concentration of which was recorded by an automatic computing ear oximeter (Sekelj *et al.*, 1958). Subsequently, the oximeter was simplified (Sekelj and McGregor, 1961; McGregor, Sekelj, and Adam, 1961) and the dye changed to Coomassie blue (0·3–0·7 mg./kg.). Heart rate was recorded by an electro-

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cardiograph. In the older children blood pressure was recorded by arterial puncture* and in the younger children by a sphygmomanometer with a cuff of appropriate size. Mean blood pressure was obtained by electrical integration in the former and by the convention of adding one-third of the pulse pressure to the diastolic pressure in the latter. Blood pressure readings were not available for the adult subjects. The hæmodynamic data were related to body weight, height, and surface area of the patients calculated from the formula of Du Bois (1936).

RESULTS

Both cardiac output and stroke volume were related closely to the size of the subject, the correlation being almost equally good for height, weight, and surface area. The correlation coefficients and the regressions relating all three parameters are shown in Table I. Because the use of the "body surface area" is so widespread in physiology, the relation between this measurement and the hæmodynamic data was further explored (Fig. 1).

The average cardiac index for the whole group was 3·38 litres per minute per square metre of body surface area (l./min./m.^{2}bsa) and the line representing the regression y (l./min.)$=3{\cdot}38\times$(m.^{2}bsa) did not differ significantly ($p<0{\cdot}4$ (Snedecor, 1961)) from the regression relating cardiac output to body surface area (Fig. 1).

The mean stroke index was 42·49 ml./beat/m.^{2}bsa and the regression y (ml./beat)$=42{\cdot}49\times$(m.^{2}bsa) did not differ significantly ($p<0{\cdot}4$) from the regression relating stroke volume to body surface area (Fig. 2).

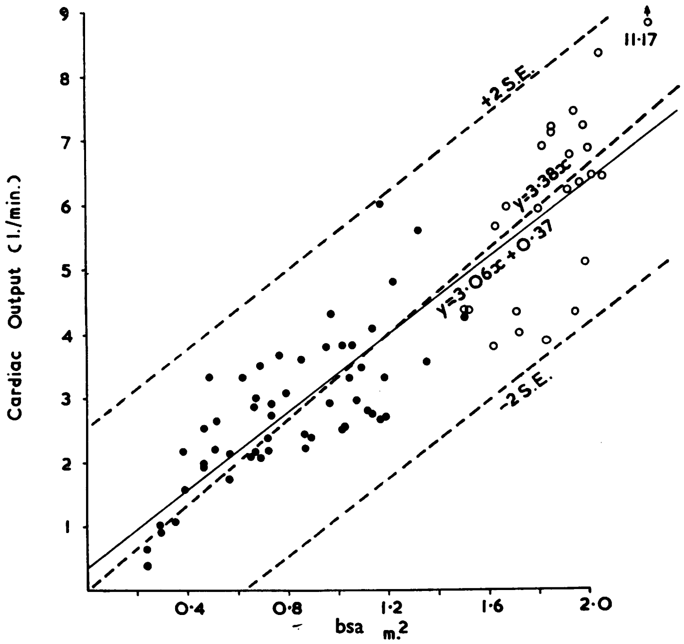

FIG. 1.—Relation between cardiac output and body surface area (bsa). Solid and parallel interrupted lines represent the regression equation relating cardiac output to body surface area with 95 per cent confidence limits. Interrupted line arising at 0 represents the relation implied by the expression cardiac index =3·38 l./min./m.^{2}bsa. Solid circles refer to children up to 15 years. Open circles refer to adults.

* Statham P23D strain gauge manometer. Sanborn twin channel direct writing recorder.

TABLE I

RELATION OF CARDIAC OUTPUT AND STROKE VOLUME WITH MEASUREMENTS OF BODY SIZE

	Body surface area ($m.^2$)	Weight (kg.)	Height (cm.)
Cardiac output			
Correlation coefficient	0·85	0·86	0·84
Regression	$y=3{\cdot}06x+0{\cdot}37$	$y=0{\cdot}066x+1{\cdot}4$	$y=0{\cdot}045x-1{\cdot}73$
Stroke volume			
Correlation coefficient	0·88	0·89	0·84
Regression	$y=47{\cdot}96x-6{\cdot}26$	$y=1{\cdot}05x+9{\cdot}59$	$y=0{\cdot}70x-42{\cdot}45$

DISCUSSION

The validity of comparing a group of adults studied without any form of sedation with a group of children under anæsthesia may well be questioned and such shortcomings should be constantly borne in mind during interpretation of results. It must be stressed, however, that the level of anæsthesia was extremely light, the subjects responding to stimulation as if in light sleep. Moreover the question should be asked whether these conditions are likely to be improved on. If sedation is completely avoided small children will always tend to react to an investigative procedure, even one as simple and rapid as this, and it is likely that any attempt to study these parameters in normal unanæsthetized children would be subject to more error due to excitement than the possible error due to depression in this study.

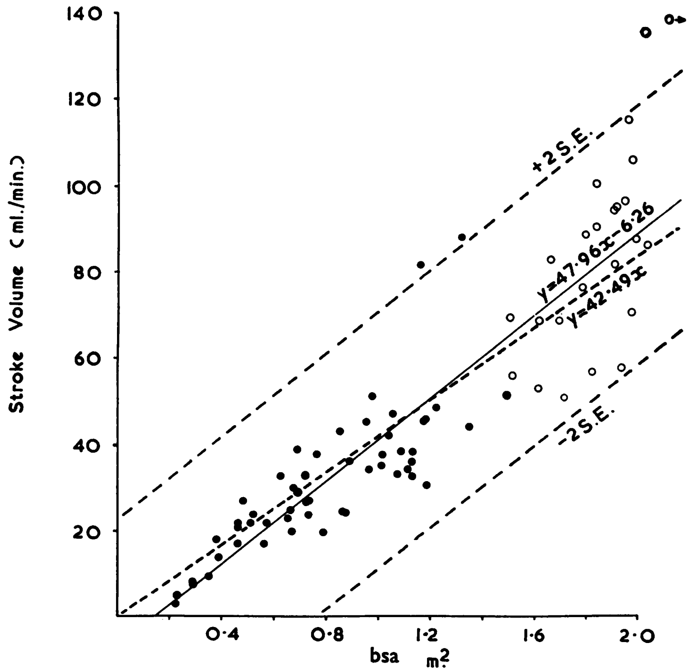

FIG. 2.—Relation between stroke volume and body surface area (bsa). Solid and parallel interrupted lines represent the regression relating these two factors with 95 per cent confidence limits. Interrupted line arising at 0 represents the relation implied by the expression stroke index= 42·5 ml./beat/m.²bsa. Solid circles refer to children up to 15 years. Open circles refer to adults.

TABLE II

MEAN CARDIAC INDEX (CI) AND STROKE INDEX (SI) OF SEPARATE AGE-GROUPS INDICATING SIGNIFICANCE OF DIFFERENCES OF MEANS

Age-groups (yr.) No. (male/female)	0–4 11/9	5–10 14/5	11–20 8/6	21–30 11/3	31–52 7/3
Mean CI	4·15	3·48	3·10	3·29	3·34
SD	1·17	0·72	0·86	0·26	0·64
Age-groups					
0–4		p<0·05	p<0·025	p<0·025	p<0·025
5–10			p=0·4	p=0·4	p=0·5
11–20				p=0·5	p=0·5
21–30					p=0·5
Mean SI	37·88	40·48	38·96	44·62	47·36
SD	11·40	7·06	13·00	10·90	10·77
Age-groups					
0–4		p=0·4	p=0·5	p=0·1	p<0·05
5–10			p=0·5	p=0·4	p=0·2
11–20				p=0·4	p=0·2
21–30					p=0·5

p values equal to or greater than 0·1 indicate that the differences of the means are not significant.

Consideration should also be given to the question of whether these parameters should best be related to height, to weight, or to body surface area. There is little evidence that Du Bois' formula truly indicates the surface area of the body, particularly in small children and infants. Furthermore, equally high correlation was demonstrated between the hæmodynamic data and body height or weight as with the "surface area" calculated from them. The latter, however, even if it remains itself somewhat of an abstraction until supported by more observations, has been widely employed for many years and has constituted the basis of standardization of much valuable data. It thus requires very strong reasons to depart from its use.

The validity of the expression "cardiac index" is indeed supported by the present data in that there was no significant difference between the line describing cardiac index=3·38 l./min./m.^{2}bsa and the respective regression equation relating the observed cardiac output and body surface area (Fig. 1). The expression "stroke index" is similarly supported by the data (Fig. 2). Despite this, in the lower range (0·3–0·5m.^{2}), it would make a considerable difference which relation was correct. It is exactly in this range that there are few data to validate the use of either expression and the assumption of a linear relation itself is quite possibly in error. Standardization of hæmodynamic data by reduction to cardiac and stroke index should thus be undertaken with caution in small children.

With this precaution in mind it is of interest to attempt to determine the influence of age on hæmodynamic parameters eliminating the effect of body size as far as is possible by use of the cardiac and stroke index, and dividing the subjects into age-groups (Table II). The cardiac index in the youngest age-group was significantly higher than the rest of the series though whether this observation truly reflects the influence of age or whether it represents incomplete elimination of the influence of body size on the data is uncertain. The absence of change in cardiac index from 10 years upwards is of interest and should be contrasted with the data of Brandfonbrener, Landowne, and Shock (1955) and Lammerant, Veall, and De Visscher (1961) who, in a study of older age-groups, each observed a progressive fall in cardiac index as age increased. Stroke index, by contrast, appears to rise slightly over the age range studied though the change is not significant except between the youngest and oldest groups (Table II). In considering both cardiac and stroke index data, however, the possible influence of anæsthesia in the children and apprehension in the adults should be borne in mind.

In a similar way, by standardizing for body surface area, the influence of age on systemic resistance could be studied. In Fig. 3A may be seen the relation between age and mean blood pressure in 53 subjects up to 15 years of age. It should be noted that all these subjects were under light anæsthesia. The technique of measuring the mean blood pressure was not the same in younger children and older children but the regression line describing the mean blood pressures in relation to age parallels the increase of systolic pressure reported by other workers (Fig. 3A), and for this reason its validity is tentatively accepted. When mean blood pressure is divided by cardiac index and related to age (Fig. 3B), a progressive increase in the "resistance index" is apparent over the age range studied.

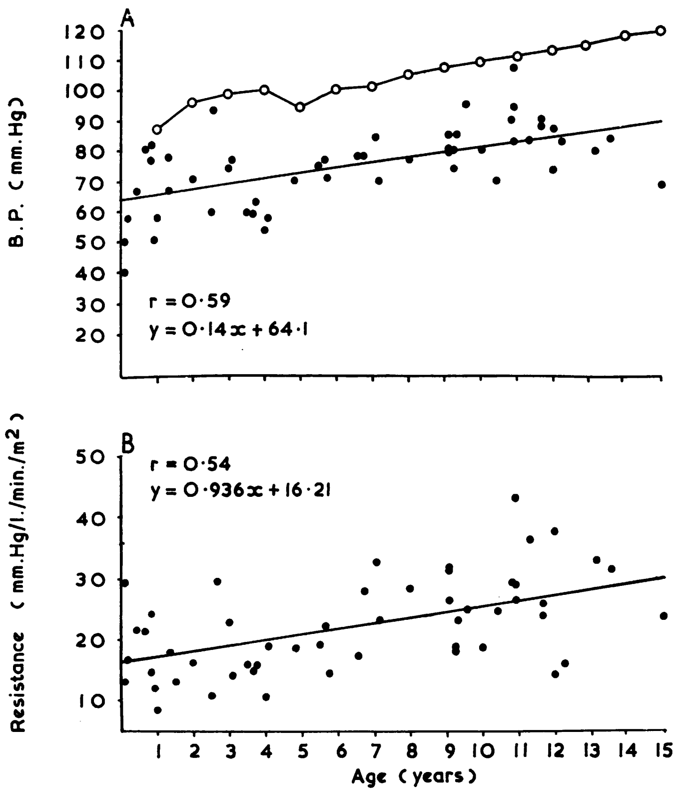

FIG. 3(A)—Relation between mean blood pressure and age up to 15 years for all subjects. Circles joined together in the age-group 1–15 years represent average systolic blood pressure reported by Allen-Williams (1945) and Gunteroth and Nadas (1955). The straight line represents the regression equation relating these two variables.

(B)—Relation between systemic resistance "index" and age. Solid line represents the regression equation relating these two variables.

Summary

Comparison was made between height, weight, and body surface area on the one hand and cardiac output measured by dye-dilution method, stroke volume, and peripheral vascular resistance on the other. Seventy-seven subjects were studied ranging in body size from 0·2–2·0 $m.^2$bsa.

Correlation between cardiac output and stroke volume with height, weight, and body surface area was high. Linear regression equations were calculated which related cardiac output and stroke volume respectively to body surface area.

The mean cardiac index was 3·38 l./min./$m.^2$bsa and the mean stroke index was 42·5 ml./beat/$m.^2$bsa. The data supported the validity of these indices as a means of eliminating the influence of body size from the hæmodynamic data.

The influence of age on the hæmodynamic parameters indicated that the cardiac index was slightly higher in young children whereas the stroke index was somewhat lower in younger age-groups. Both blood pressure and systemic resistance index showed an increase up to age 15 years.

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