DIGITAL DATA PROCESSING CHANGES OLD STATEMENTS ABOUT BLOOD VOLUME AS A FUNCTION OF BODY DIMENSIONS

HARRY HERSCOVICI, PH.D.
Associate Professor
Department of Biomedical Engineering
University of Miami
Coral Cables, Florida

MARTIN TERRIS, PH.D.
Consultant
Cordis Research Corporation
Miami, Florida

THE sole reference treating blood volume as a function of body dimensions quoted in A.C. Guyton's *Textbook of Medical Physiology*[1] is "Clinical Studies of Blood Volume" by J.G. Gibson II and W.A. Evans, Jr.[2] It remains so in Guyten's 6th edition, 1981.[1] Gibson and Evans attached all data collected in their investigations to their paper. They did not, however, include their regression formulae.

Gibson and Evans[3] conclude that blood volume remains constant in women with any increase in surface area over 1.6 m^2 or weight over 60 Kg, while in men it continues to increase. They also claim that blood volume per unit of body surface, weight, and height[4] present maxima for women, and that blood volume per unit of weight presents a maximum also for men.

These conclusions are difficult to understand physiologically. Blood supply increases to meet increased body needs, and all tissues need blood, even those added by women as their weight climbs above 60 Kg. We reprocessed Gibson and Evans' data (using an RS/1 software package in a Digital PC 350 computer)* to determine how well warranted their conclusions are and to see whether statistically they really are the only possible conclusions.

First we sought the mathematical equation of the regression curve plotted by the authors themselves. We found second degree equations for all the

*. . .*RS/1 Command Language Guide*. BBN Research Systems, 1982, pp. 7-8 to 8-14.

relationships between blood volume and body surface area ($V_B=F(S)$), body weight ($V_B=F(W)$), and body height ($V_B=F(H)$):

$$V_B=-2.42S^2+12.75S-9.71 \quad \text{males}$$
$$V_B=-6.03S^2+20.99S-14.04 \quad \text{females} \qquad (1)$$

$$V_B=-5.40.10^{-4}W^2+0.14W-1.38 \quad \text{males}$$
$$V_B=-2.01.10^{-3}W^2+0.26W-4.28 \quad \text{females} \qquad (2)$$

$$V_B=-13.24H^2+52.16H-45.2 \quad \text{males}$$
$$V_B=-3.07H^2+12.41H-8.21 \quad \text{females} \qquad (3)$$

Second, we looked for possible linear regressions to describe their data. The following linear equations can also represent the data collected by Gibson and Evans:

$$V_B=3.61S-1.22 \quad \text{males}$$
$$V_B=2.33S+0.19 \quad \text{females} \qquad (4)$$

$$V_B=0.06W+1.1 \quad \text{males}$$
$$V_B=0.027W+2.27 \quad \text{females} \qquad (5)$$

$$V_B=6.3H-5.65 \quad \text{males}$$
$$V_B=2.43H-0.11 \quad \text{females} \qquad (6)$$

In all the above equations V_B is in liters, S in m^2, W in Kg and H in m. The most important statistical indicators are presented in the table. In comparing the results of the second degree approximations with the linear approximations, one can see that there are no significant statistical differences between the two mathematical approximations. At least for the domains of body dimensions:

Men: $S \cong 1.4$ to $2.3\ m^2$ $W \cong 45$ to 95 Kg $H \cong 152$ to 190 cm
Women: $S \cong 1.3$ to $1.8\ m^2$ $W \cong 42$ to 80 Kg $H \cong 142$ to 185 cm

But, if mathematically the two approximations are equally valid, physiologically the linear approximations lead to very different conclusions than the ones found by Gibson and Evans.

STATISTICAL INDICATORS OF SECOND DEGREE AND LINEAR APPROXIMATIONS OF THE BLOOD VOLUME AS A FUNCTION OF BODY DIMENSIONS

		Correlation coeff.		*Standard deviation*	
		Male	*Female*	*Male*	*Female*
Surface area	Second degree	0.79	0.67	0.50	0.35
	Linear	0.77	0.64	0.52	0.36
Weight	Second degree	0.75	0.65	0.55	0.35
	Linear	0.74	0.51	0.55	0.42
Height	Second degree	0.72	0.38	0.57	0.43
	Linear	0.70	0.38	0.58	0.43

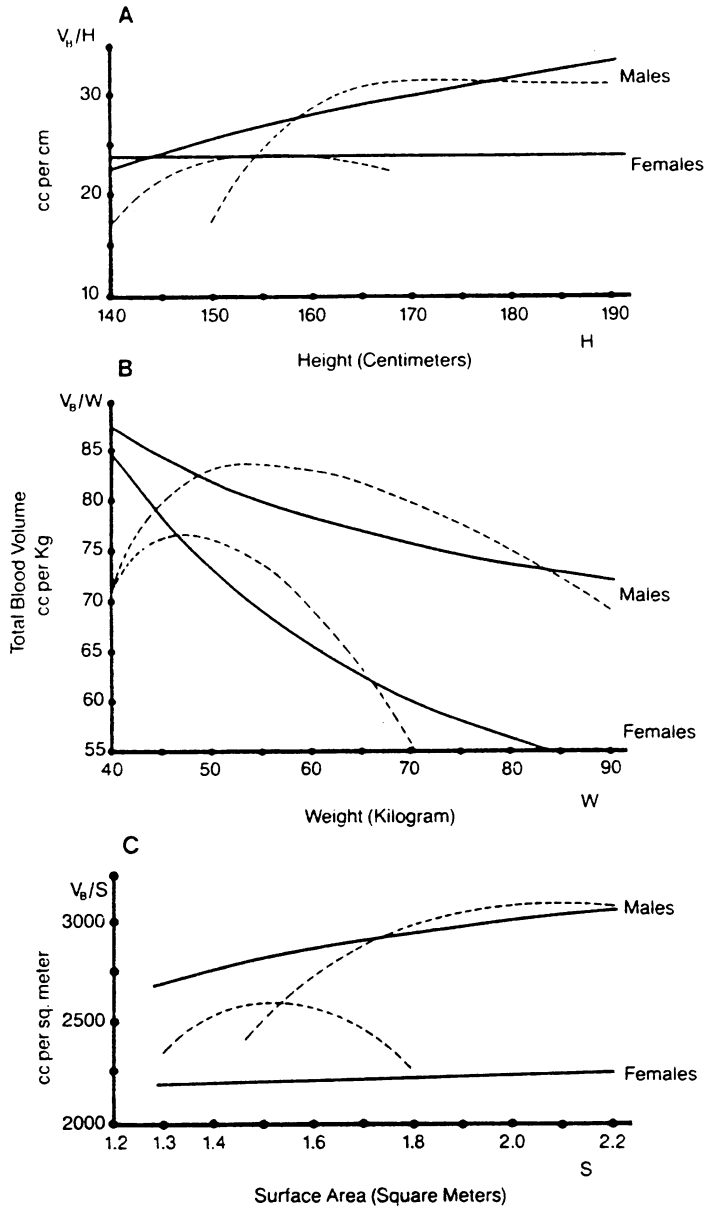
First, linear equations show a monotonic increase of total blood volume with surface area, weight, and height for men as well as for women. This looks much more reasonable than Gibson and Evans' assumption that women over 60 Kg or with surface area over 1.6 m^2 have no increase in their blood volume.

Second, the linear equations lead to different relationships between blood volume per unit of blood surface area (V_B/S) body weight (V_B/W) and body height (V_B/H).

As it is shown in the figure, based on a linear approximation, V_B/S and V_B/H for women are rather invariant with S or H while they are monotonically increasing for men. Both men and women show a decrease in V_B/W with the increase of W. In other words, for men the quantity of blood per square meter of surface area or cm of height increases with the increase of body surface or body height while for women it is essentially invariant. As for the weight, both in men and women the blood volume per unit of weight diminishes because fatty tissue has little vascular volume. Furthermore, for women who have higher ratios of fatty tissue to lean tissue than men, the blood volume per unit of weight decreases much faster than for men.

Conclusions

If the relationship between total blood volume and body surface, height, and weight can be considered linear and expressed by equations (4), (5), and (6), then the following conclusions are evident: Blood volume increases proportionally with body surface, height, and weight for both men and women; blood volume per unit of weight decreases with body weight for both men and women, more rapidly for women; and blood volume per unit of body surface and body height increases almost proportionally with body



A—Correlation of blood volume per unit of height with body weight. B—Correlation of blood volume per unit of weight with body weight. C—Correlation of blood volume per unit of surface area with body surface area. Dotted line: Gibson and Evans results. Solid line: Results based on the linear approximation.

surface and respectively body height for men and is almost invariable for women.

These conclusions contradict Gibson and Evans' conclusions, but they look more reasonable physiologically. There is no reason that big or heavy people have proportionally less blood than small or light people. There is no reason that women heavier than 60 Kg have the same quantities of blood as women weighing just 60 Kg. There is no reason that people weighing more than 55 Kg for men and 47 Kg for women to have less blood per Kg than people with exactly this weight.[5] The maxima required by Gibson and Evans' approximations are meaningless.

SUMMARY

Reprocessing data collected by Gibson and Evans in 1937, it was found that, contrary to their conclusions, the correlation between blood volume and body dimensions may be described as linear, increasing in proportion to body surface, height, and weight for both men and women. We also found that blood volume per unit of body weight decreases as body weight increases in both men and women. Blood volume per unit of body surface and body height increases for men and is constant for women.

Gibson and Evans' conclusions stated that for certain body weights and surface areas, blood volume presents limitations, while blood volume per unit of body surface, height, and weight present maxima. Even if mathematically these conclusions are correct, physiologically they look strange.

Our conclusions are compatible with both the mathematical aspect and the physiological one.

REFERENCES

1. Guyton, A.C.: *Textbook of Medical Physiology.* Philadelphia, Saunders, 1981, p. 393; 5th edition, 1976, p. 426.
2. Gibson, J.C. II, and Evans W.A., Jr.: Clinical studies of blood volume. *J. Clinic. Invest. 16:*317-328, 1937.
3. Ibid., Figure 4.
4. Ibid., Figure 5.
5. Ibid., Figures 4, 5.