Plasma and Blood Volumes in Severely Malnourished Jamaican Children

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Oedema and expansion of the extracellular fluid are well recognized as a complication of malnutrition in adults (McCance, 1951) as well as in children (Waterlow, Cravioto, and Stephen, 1960). An increase in total body water has also been described (Srikantia and Gopalan, 1957; Schnieden, Hendrickse, and Haigh, 1958; Smith, 1960). In the course of investigations on the renal function of malnourished children, a severe reduction in glomerular filtration rate was found (author's observations), and it became necessary to establish that in the children studied there was no reduction in circulating plasma or blood volume to account for these changes. The results of these determinations are now described.

Material and Methods

Seven male malnourished children were studied as soon after admission as possible and at intervals during their hospital stay, while they were recovering from malnutrition.

In all cases, protein-calorie malnutrition was the primary illness, and the clinical picture corresponded to that described and reviewed by Waterlow *et al.* (1960). There were 4 children with, and 3 without oedema on admission. The treatment of these children was as set out by Garrow, Picou, and Waterlow (1962) and consisted essentially of graduated feeds, therapy of infection, administration of ferrous sulphate and folic acid orally and of potassium supplements to restore deficits which invariably occur in malnutrition (Garrow, 1965).

Plasma volume was determined by isotope dilution after the intravenous injection of ^{131}I -labelled human serum albumin containing 1-2 μC . A single sample of blood was withdrawn 10 minutes after the ^{131}I injection and the plasma activity determined in a well type scintillation counter. The haematocrit was measured in a Hawksley micro-haematocrit centrifuge with capillary tubes. The blood volume was calculated as:

$$\text{Plasma volume} \times \frac{100}{100 - \text{WBH}} \quad \text{where WBH (whole body haematocrit) = corrected venous haematocrit} \times 0.91$$

(Chaplin, Mollison, and Vetter, 1953). Plasma volumes were measured initially within 4 days of admission and at varying intervals until recovery.

Results

In every case there was a rise in the absolute plasma volume as the child recovered (Table). When expressed per kg. body weight, the plasma volume fell with recovery, and in Fig. 1 is shown the relation between plasma volume expressed as ml./kg. body weight and the weight deficit. As the children recovered and approached their ideal weight, there was a fall in their plasma volume per kg. body weight. The mean plasma volume in the malnourished children was 62.9 ml./kg. (range 42.4-76.6) and after recovery 49.3 ml./kg. (range 44.0-56.6). The difference is significant ($p < 0.05$). The absolute blood volume also rose with recovery, but there is no significant difference between the

FIG. 1.—Plasma volumes in malnourished and recovering children related to their percentage expected weight for height ($y = -0.4x + 91.4$).

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TABLE
Absolute Plasma and Blood Volumes in the 7 Children

Child	Age on Admission (mth.)	Days After Admission	Body Weight (kg.)*	Weight as % of Expected Weight for Height	Plasma Volume (ml.)	Blood Volume (ml.)
D.M.	9	1	8.78 (8.12)	88.3	344	549
		10	8.12	89.9	383	581
		35	9.35	97.2	491	667
		50	9.50	104.0	442	596
L.N.	14	2	5.80 (5.43)	65.0	369	402
		12	5.50	65.9	358	511
		54	7.14	81.6	423	629
		109	9.36	96.0	412	639
J.G.	15	1	7.14 (7.02)	73.1	342	482
		12	7.02	73.1	350	476
		81	9.62	95.7	464	700
H.G.	8	2	4.15 (3.90)	84.8	244	324
		14	4.46	97.0	309	422
		50	5.68	98.8	276	399
S.M.	18	3	4.65	69.4	316	382
		11	5.00	66.7	306	421
		29	6.05	77.6	372	534
		129	8.74	95.5	419	632
J.F.	11	1	4.50	67.2	332	410
		12	4.60	66.2	286	393
		69	6.62	92.6	386	582
		118	7.94	92.9	449	659
A.W.	9	4	4.32	72.6	331	414
		47	5.54	87.9	324	451
		75	6.65	99.3	401	580
		123	7.86	104.1	422	620

* The figures in brackets for the first 4 children represent the minimal weight after they had lost oedema.

FIG. 2.—Relation of plasma volume to corrected venous haematocrit (peripheral venous haematocrit $\times 0.91$)
($y = -0.02x + 86.06$).

blood volumes expressed as ml./kg. body weight in the malnourished and recovered children. The mean values are 80.4 ml./kg. (67.6-95.8) for the malnourished children and 72.6 (62.7-83.0) for the recovered children $p > 0.1$. The relationship of the plasma volume to the venous haematocrit is shown in Fig. 2. The falling plasma volume correlated with a rising venous haematocrit.

Discussion

The estimation of plasma volume by determining the activity in a sample of plasma taken 10 minutes after the injection of a suitable tracer assumes that there is rapid uniform mixing within the intravascular space. This has been shown in dogs by Wasserman and Mayerson (1951) who found almost identical activity in samples drawn from different sites. In addition, the relatively slow rate of disappearance of the label initially makes a single 10-minute sample reliable enough for all practical purposes. It is appreciated that the method used here for measurement of blood volume is not ideal

and it would have been preferable to measure red cell mass and plasma volume independently. The assumption also that the ratio of whole body haematocrit to peripheral venous haematocrit holds true for malnourished children was not validated in this study. Several workers have reported on the increased plasma volume occurring in malnutrition, irrespective of the methods used (Gollan, 1948; Gomez, Ramos Galván, Cravioto Muñoz, and Bienvenú, 1950; Cohen and Hansen, 1962; Picou, 1963). Gomez *et al.* (1950) used Evans Blue and found a mean value for plasma volume of 83 ml./kg. in malnourished children compared with 62 ml./kg. in normal subjects. These values are unaccountably much higher than those found in the present or any other study. They also showed that the increase in plasma volume per unit body weight could be related to the weight deficit.

Cohen and Hansen (1962) observed mean values of 61 ml./kg. and 51 ml./kg. for the malnourished and recovered children, respectively, and Picou (1963) obtained figures of 60 ml./kg. and 50 ml./kg. for malnourished and recovered children. These values are all strikingly close to the ones obtained in this study. The blood volume for recovered children (72.6 ml./kg.) is also close to the 71.5 ml./kg. given by Russell (1949) for 64 normal children of similar ages to the ones studied here. Gomez *et al.* (1950) again had higher values than these for blood volume—135 ml./kg. in malnourished and 105 ml./kg. in normal children. Their finding of a statistically significant difference in blood volumes between malnourished and recovered children was not substantiated in the present study.

The concept that the increase in body water constitutes a response to the reduction in body solids (Smith, 1960) may well be applied to the blood. The plasma volume is closely related to the venous haematocrit, and with rising haematocrit there is a fall in plasma volume. Meanwhile there is no trend in blood volume changes. This seems to indicate that the blood behaves as other tissues and there is a compensatory increase in the liquid phase with decrease in the solid phase. This decrease of plasma volume with increasing haematocrit is not peculiar to malnutrition, but has been demonstrated previously in such conditions as pernicious anaemia (Gibson, 1939). Other attempts to explain the relative increase in plasma volume in malnutrition, e.g. increased aldosterone production,

have not been substantiated. Indeed, Lurie and Jackson (1962) measured urinary aldosterone levels in kwashiorkor patients but could not demonstrate any significant increases.

Summary

Twenty-six determinations of plasma and blood volumes were done in 7 malnourished Jamaican children, on admission to hospital and as they recovered. There was a fall in plasma volume expressed per unit of body weight but no change in blood volume. There were significant correlations between the plasma volume changes, the weight deficit, and the venous haematocrit.

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