"Saturovolaemia"

A new concept in the aetiology of toxaemia of pregnancy

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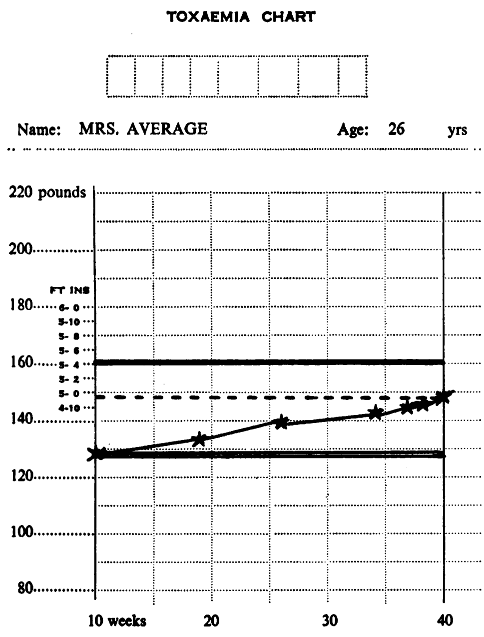
IN a previous paper I have described the construction and use of the 'Toxaemia' chart. Briefly this chart is a weight chart, for use during pregnancy, having horizontal lines drawn in at those weights which were found to be desirable for the start and finish of a normal pregnancy and also a third 'toxaemic' weight line above which it was undesirable for a pregnancy to go, lest it begin to show early signs of toxaemia. This 'toxaemic weight' represented 2.50 pounds per inch of the patient's height and the prediction error in the use of this chart has been found to be not much more than ten per cent. Two examples of this chart in use are shown in figures 1 (a) and 1 (b). The chart as a diagnostic tool in the antenatal clinic has many uses which are outside the purpose of the present essay.



Comments:
NORMAL PREGNANCY. (Height 5ft. 4 in.)

Figure 1 (a)

INSTRUCTIONS

"TOXAEMIC" WEIGHT

Draw a horizontal black line through the patient's height on the height scale.

"NORMAL" WEIGHT AT TERM

Draw a horizontal broken line 13 pounds lower than the broken one.

"IDEAL" WEIGHT AT 10 WEEKS OF PREGNANCY

Draw a horizontal double line at that weight in pounds which is double the patient's height in inches.

6 stone = 84 lbs.	11 stone = 154 lbs.
7 stone = 98 lbs.	12 stone = 168 lbs.
8 stone = 112 lbs.	13 stone = 182 lbs.
9 stone = 126 lbs.	14 stone = 196 lbs.
10 stone = 140 lbs.	15 stone = 210 lbs.
16 stone = 224 lbs.	

REVERSE SIDE OF CHART

The foundation of the chart, however, was the simple relationship of weight and height in each patient and was discovered by reducing the patient's height to one inch and expressing the weight as so many pounds per inch in height. The initial survey was conducted on a series of 250 cases and later the conclusion was confirmed in a further series of 400, followed by its application in day-to-day usage.

Normal pregnancies usually come to term at less than 2.50 pounds per inch in height and pregnancies where the traditional signs of toxaemia are present are above this weight in four pregnancies out of five.

Thus over the last four years it has been established clinically that height, as well as weight is an important factor in the consideration of toxaemia.

As far as I know height has not been put forward before among the arguments in the consideration of the aetiology of toxaemia. That it must be is borne out clinically in the use of the toxaemia chart and an explanation of toxaemia must involve something which has a relationship to height as well as weight. Moreover, in a single patient where the height is constant, one pregnancy may be normal and another be toxaemic, only the weights of the two pregnancies being different. And yet again two patients, being before pregnancy quite normal, may be of similar weight at term, but being of differing heights the one may be normal and the other toxaemic. If therefore the possibility of toxaemia is predictable on a height-weight basis alone, then there must be a physiological basis to it.

Those systems in the body which vary with the height of the person are the skeletal system, the nervous system and the cardiovascular system, but of these only the cardiovascular system varies materially with the weight of the person as well. A gain or loss in body weight does not affect the bulk of the nerves, the size of the long bones or the shape of the blood vessels going to make up the cardiovascular system, but a gain or loss in weight is reflected in the blood volume contained within the cardiovascular system. This increase or decrease in blood volume according to gain or loss in weight is predictable using normograms, such as that described by Hicks, Hope, Turnbull and Verrell (1959). These normograms are also used in conjunction with Blood Volume Computer machines.

Therefore blood volume satisfies the criteria of something which varies with height and weight as required by the use of the toxaemia chart and it is known than it does increase very much during pregnancy.

Theory

Whereas blood vessels may contract or dilate, their length does not vary. They are all tubular in shape and the volume of a section of any one of them is $l\pi r^2$ where l is the length of the section concerned (be it capillary, arteriole or dorsal aorta). Moreover the sum total of all these vessels could be written as $H\pi r^2$ where 'H' is the height of the person concerned and $H\pi r^2$ is now the total capacity of the cardiovascular system. If the radius of any of these blood vessels was "r_m" when it was dilated to its fullest capacity, the maximum capacity of the cardiovascular system would become $H\pi {r_m}^2$. Since all major blood vessels are comparable anatomically as between one person and another this formula gives a basis of comparison between one person and another. 'H' or height is the largest variable factor in it (for even 'r_m' or the maximum radius of a blood vessel, will in itself vary with the height of the person). Excluding very thin or very broad body types or builds, the maximum capacity of the cardiovascular system among comparable persons will vary according to the formula $H\pi {r_m}^2$ and any variation there is will be very largely in proportion to their differences in heights.

If any of these people grow fat, their blood volume will increase and occupy more of the cardiovascular system. The size of their main blood vessels has been designated at birth and these can only expand to their limit, they cannot increase in size or number. When the blood volume increases in a system whose maximum capacity remains unchanged, can there be a limit to the increase in blood volume which occurs? Manifestly there can. If it were possible to increase the blood volume of a healthy young adult by five ml every day this process could not go on indefinitely. The body may be full of by-pass mechanisms to allow an increased blood flow to certain organs so that they can fulfil their function when called upon to do so, but in the ordinary way, day after day, these reservoir facilities would not be available to it. Eventually some signs of strain would emerge. There must come a time when the body would have to cry "halt" and try and contain this rising tide of blood volume. And yet a similar process of a steady increase in blood volume occurs during every pregnancy. Is it possible that it sometimes reaches undesirable limits when signs of stress and strain appear? Is there anything in the clinical picture of toxaemia compatible with the concept of too great an increase in blood volume?

Clinical picture

The clinical picture in toxaemia is of a cardiovascular system that is at bursting point and at post-mortem there is evidence of haemorrhage into many important organs.

1. *The Brain*	In the brain there may be small haemorrhages, necrosis and clinically convulsions
2. *The Eye*	Retinal haemorrhages may occur and sometimes lead to retinal detachment
3. *The Liver*	In the liver there is haemorrhagic necrosis of the periphery of the hepatic lobule and a subcapsular haemorrhage has even been known to rupture through into the peritoneal cavity
4. *The Kidney*	In the kidney there may be interstitial haemorrhages and thrombosis of afferent glomerular arterioles
5. *The Adrenals*	There may be small haemorrhages and necrosis in the adrenal glands
6. *The Uterus*	Accidental haemorrhage is a well known complication
7. *The Blood Vessels*	Minor episodes such as bulging varicose veins, haemorrhoids and epistaxis are common
8. *Blood Pressure*	One of the traditional early warning signs of toxaemia is a rise in blood pressure
9. *Treatment*	Relief is brought to a toxaemic patient by putting her to rest. Even in these days of early ambulation in nearly every other field, only complete bed rest will bring respite to toxaemia of pregnancy. Temporary relief may also be brought with the use of diuretics. Both of these measures help to lower the blood volume.

Therefore the clinical picture of toxaemia is compatible with a cardiovascular system which is at bursting point, but why does this occur in one pregnancy and not another?

"Saturovolaemia"

The toxaemia chart emphasizes that it is the overweight patients who will go on to develop toxaemia (figure 1 (b)). A girl who is overweight at the start has an initial blood volume which is greater than that of her slimmer counterpart. She can be said to be "hypervolaemic". Starting pregnancy with too much blood it is possible that she cannot accommodate the increase in blood volume due to the pregnancy itself and later reaches saturation point and is distressed, the signs of which we have come to recognize as toxaemia. She has reached a condition of 'saturovolaemia'.

This is the position when, in the previous theory, the cardiovascular system had reached its maximum capacity and had had to cry "halt". The signs of distress are the well-known triad, oedema, rise in blood pressure and albuminuria. Signs of congestive heart failure are not evident for these are for the most part healthy young girls whose hearts are well able to cope with the extra load demanded of them.

The slimmer colleague, being isovolaemic, has less blood at the start of her pregnancy and will have room for the increase in blood volume due to the pregnancy itself. Her pregnancy continues to term normally, with no signs of distress.

It is at the point of 'saturovolaemia', or the onset of toxaemia, that various other mechanisms come into play. There will be enormous pressure upon the circulation, especially during uterine contractions, and that this is so has been proven by I. Cunningham (1970) using intracardiac techniques. Such intermittent rises in pressure might overwhelm the delicate renal glomeruli. But at this point there is generalized vasoconstriction and both the arteriolar spasm and the rise in pressure in the renal artery probably triggers off the Trueta shunt mechanism by which the glomeruli are by-passed. This results in salt and water retention, clinically evidenced as widespread oedema. Should this spasm go on for too long it might result in an irreversible change evidenced by bilateral renal cortical necrosis.

Even during a normal pregnancy there is a large increase in blood volume, and this will put serious pressures upon the renal circulation during uterine contractions. Therefore it would be desirable to have an advance warning of their coming. There is such a mechanism in the utero-renal reflex described by J. Sophian (1953).

During pregnancy, anything which exaggerates the rise in blood volume will precipitate the condition of 'saturovolaemia'. Therefore multiple pregnancy with two or more placentae to sustain will lead to an earlier and larger rise in blood volume and this may reach the limits sooner. Diabetes with its general metabolic upset and circulatory changes may do the same.

Conversely, anything which reduces the potential capacity of the cardiovascular system will lower the physiological limits and bring on toxaemia earlier. Thus, essential hypertension, with its vasoconstrictor mechanism, will bring it on sooner and so may such allied conditions as thyrotoxicosis and Raynaud's disease. Even patients with chilblains seem to succumb sooner. The rare condition of hypoplasia of the aorta has been described by C. A. B. Clemetson (1960) and found to do the same thing.

After delivery there is a gradual loss of the placental lake and much of this blood must be assimilated into the maternal circulation. Where this is difficult, because it is already filled to maximum capacity, the extra blood may prove too much and provoke postpartum convulsions. However, a few hours after delivery the mother will have effected a reduction in blood volume by diuresis and the danger of convulsions grows less.

This concept does help to explain the clinical behaviour of toxaemia and why it might be expected to appear earlier under certain circumstances and not arise in others. It also supplies an explanation of why toxaemia may arise in association with a hydatidiform mole. A rapid rise in blood volume in an overweight patient, trying to supply the needs of a sanguineous or quickly growing vesicular mole, could reach the stage of 'saturovolaemia' and so give rise to the signs of toxaemia.

Present research

'Saturovolaemia' expresses a theoretical concept and at the same time agrees with the clinical picture of toxaemia. Therefore it should be possible to demonstrate that the blood volume is greater in toxaemic patients than it is in normal patients. This has already been done by C. J. Rominger (1964) in America using radioactive isotope techniques. But also it ought to be possible to decide at what level a 'normal' pregnancy blood volume reaches a ceiling level above which abnormalities begin to appear.

In this enquiry, in order to compare one patient's blood volume with another, the height factor was eliminated by expressing all blood volumes as millilitres per inch of the patient's height. Two groups of patients were selected the aim being to compare typical normal pregnancies on the one hand with the onset of typical straight-forward toxaemias on the other. Both had a common starting weight on the toxaemia chart, i.e. near the double black starting line. Neither had any abnormal features, e.g. essential hypertension, renal disease, glycosuria, anaemia, or hydramnios, and both groups gave birth to a single, live, healthy baby.

The first group was entirely normal throughout and came to term below the black 'toxaemia' line (figure 2 (a)). A blood volume was done near term. The second group

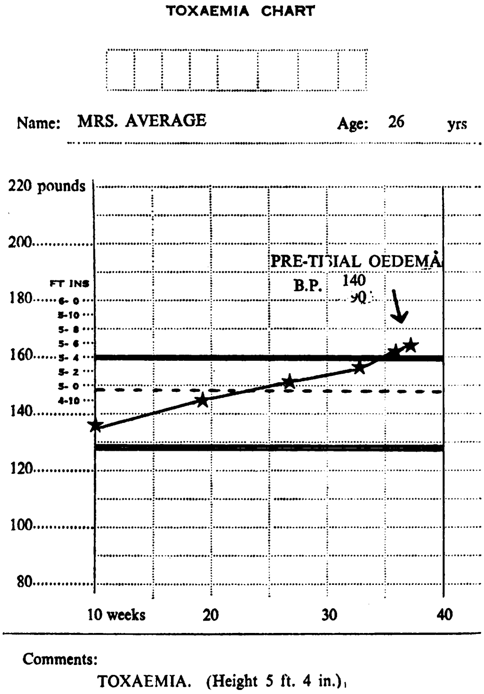


Figure 1 (b)

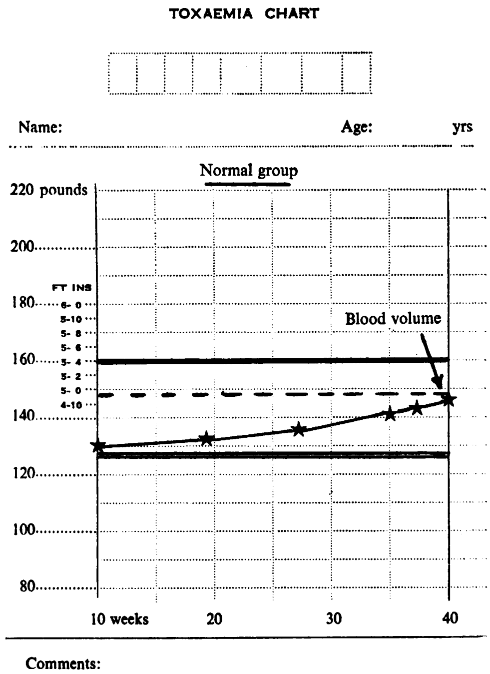


Figure 2 (a)

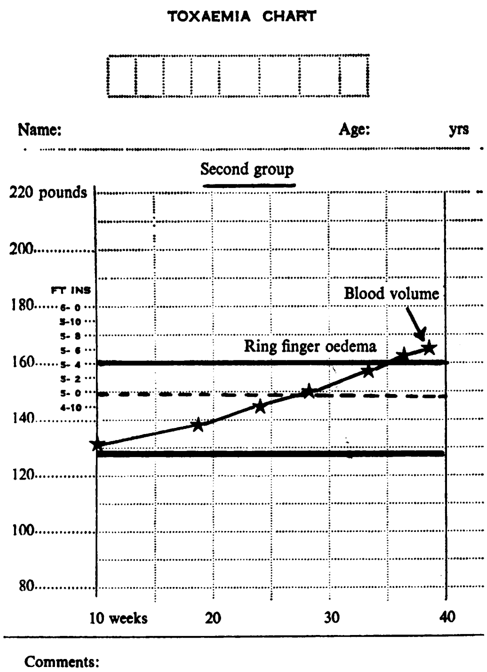


Figure 2 (b)

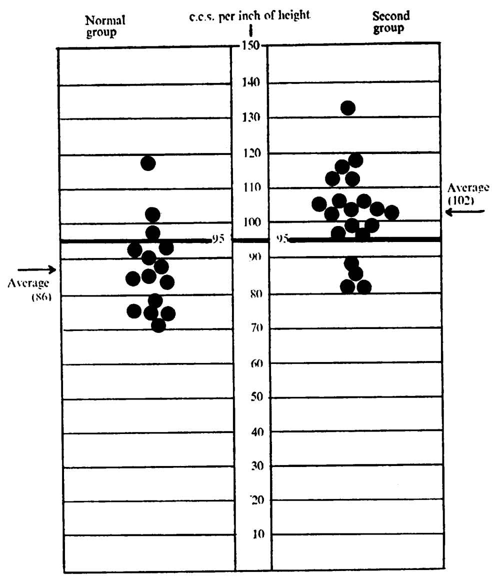


Figure 3

(figure 2 (b)) who all showed early signs of toxaemia had risen above the 'toxaemia' line and a blood volume was done when they first began to show any signs of distress or toxaemia. The blood volumes were carried out using the methylene blue method and the estimations made by a disinterested laboratory. Their results, expressed as total blood volumes, were recalculated as c.c.s per inch of the patient's height (figure 3).

It was found that the majority of the normal pregnancies came to term at less than

TABLE

Initials	*Height inches*	*Age*	*Parity*	*Plasma volume*	*Total volume*	*Percentage Plasma volume*	*c.c.s. Blood per inch height*
				NORMAL GROUP			
C.L.	63	21	1	4,860	6,460	75.2	102.5
M.P.	60½	20	0	4,500	7,150	63	118.1
M.V.	63½	30	0	4,300	6,060	71	95.6
J.P.	63	21	1	3,530	5,400	65.4	85.7
U.F.	62½	26	1	2,970	4,680	63.5	75
A.H.	63	25	1	3,660	5,660	64.7	90
L.T.	64	44	8	3,700	6,000	61.7	93.4
V.E.	62½	27	1	2,880	4,400	65.5	70.5
S.L.	61	21	2	3,050	4,530	67.4	74.3
M.T.	63½	19	0	3,570	5,370	69.6	84
S.R.	60½	26	0	2,960	4,720	62.6	78
B.R.	62	33	2	3,300	5,250	62.8	84.7
M.C.	63	27	1	3,760	5,600	67	89
C.P.	64	21	1	3,140	4,840	65.8	75.5
J.H.	64¾	22	0	3,650	6,000	61	92.5
				SECOND GROUP			
M.W.	66	24	0	4,540	6,580	69	99.6
E.H.	63	32	3	3,360	5,060	66.5	80.3
R.H.	60	35	1	4,440	7,100	62.5	118
E.S.	63	39	2	4,060	6,570	61.8	104
P.H.	63	31	2	4,920	7,050	69.8	112
J.J.	61½	20	0	4,000	6,480	61.7	105
B.G.	65	27	3	5,250	7,500	70	115.2
M.W.	69	26	0	3,350	5,130	65.4	80.2
S.C.	63	21	2	4,190	6,050	69.3	96
M.B.	62½	23	0	4,310	6,620	65.2	106
B.W.	63	33	1	5,820	8,400	69.3	133
G.S.	65	27	0	3,740	5,800	64.5	89.2
D.E.	62	25	2	4,130	6,480	64	104.5
J.H.	68½	29	4	4,510	7,180	63	104
S.S.	65½	21	0	4,160	6,270	66.5	95.7
S.W.	63	32	2	4,380	6,420	68.4	102
M.B.	66	26	1	3,880	5,540	70.2	84
J.P.	62¾	20	0	4,410	7,000	63	111
J.W.	61¼	23	0	4,320	6,100	70.8	99.5
J.S.	63½	22	0	4,225	6,625	64	104

95 ml per inch of height and that their average was 86 ml per inch of height. In the second group (those showing the first signs of toxaemia) the majority were more than 95 ml per inch of height and were 102 ml on average.

Blood dilution was not a factor in that a plot showing the percentage of plasma volume to total blood volume showed no significant difference in either group (figure 4).

The average patient attending our clinics is known to be 5 ft. 4 in. in height. In the normal group she would therefore have a blood volume of 64 x 86 ml=5,504 ml, and in the second group 64 x 102 ml=6,528 ml, which is a difference of 1,024 ml or roughly one litre.

According to the normogram mentioned earlier, a patient of 5 ft. 4 in. having a starting weight of 128 pounds might be expected to have an initial blood volume of 4,210 ml. This would give an increase for our normal pregnancy of 5,504 ml less 4,210 ml

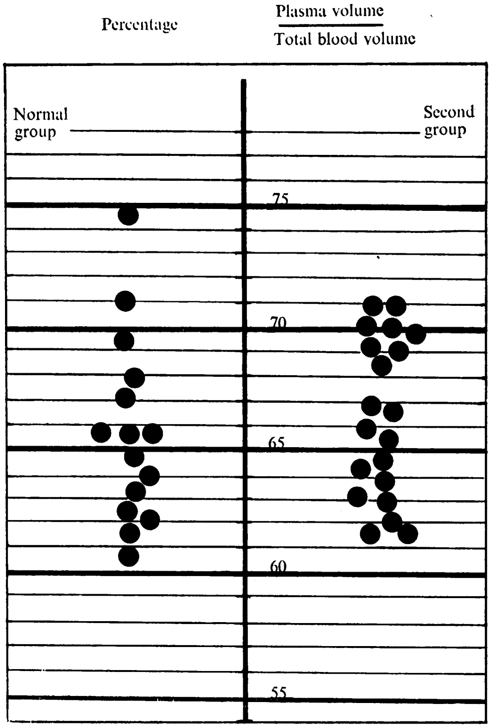


Figure 4

=1,294 ml, or approximately 1,300 ml. This increase amounts to 31 per cent of the initial blood volume and is in agreement with the findings of Low, Johnson and McBride (1965) who recorded an average figure of 30 per cent.

In the second group the increase is 6,528 ml less 4,210 ml=2,318 ml (or approximately 2,300 ml) and is an increase of 55 per cent. This increase is substantial. The two groups were distinguished only by their divergent progress on the toxaemia chart. No attempt was made to relate the differences to parities and age groups because of the inherent difficulties of doing blood volumes on large numbers of patients, but these particulars are tabulated in the table.

Discussion

These figures show that there is a difference of one litre between normal patients at term and those at the onset of toxaemia. This is much greater than the difference one might expect due to their differences in weight alone, i.e. approximately 220 ml.

The rise in blood volume during every pregnancy must be designed by nature to meet the huge demands of the growing foetus and in slim girls with normal pregnancies no difficulties arise. However, in overweight girls the rise in blood volume reaches the point of physiological saturation and then nature is trying to supply the needs of a growing foetus against a general process of vasoconstriction by which the body is striving to contain the rise in blood volume. The uterine blood vessels which are also involved in this vasoconstrictive process limit the blood supply to the foetus via the placental site resulting in placental insufficiency. This reduction in blood flow at the placental site may be as much as one third of the normal (McClure, Browne and Veall 1953). Thus nature redoubles its efforts to increase the blood volume to cope with the deficiency to the foetus. A vicious circle has now arisen and the visible signs of the stress involved are manifested as toxaemia and distress on the part of the foetus. Permanent relief can only come with the termination of the pregnancy.

Conclusion

If toxaemia can be accepted as the physiological manifestation of 'saturovolaemia' in the young female then its behaviour in association with other complications such as essential hypertension and multiparity can be more easily understood.

To avoid toxaemia the blood volume must not rise above saturation level and this requires that it be suitably low at conception. This can only be achieved in practice by seeing that a patient starts her pregnancy near the 'green' line on the chart (i.e. that weight in pounds which is equivalent to twice her height in inches).

When this is done and the weight gain controlled, then the blood volume will be contained within normal limits and toxaemia will not arise. Thus toxaemia is a preventable disorder and when there are no other complicating factors present, it should not arise. Perhaps one day it will become a thing of the past.

Acknowledgements

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Organization and management of health centres. RONALD GIBSON, *C.B.E.*, LL.D., F.R.C.S., F.R.C.G.P. *British Medical Journal.* 1970. **2,** 353.

Based on his visits to a number of health centres Dr Gibson makes the following suggestions: (1) 'Trial runs' of the new organization before going into action, (2) adequate parking facilities for patients as well as for doctors and auxiliary staff, (3) avoidance of noise and bustle and easy communications between departments, (4) the provision of 'floating' receptionists, who could be students, to help during peak periods, (5) 'breaking up' the waiting area to avoid an institutional atmosphere, (6) larger examination rooms, (7) facilities for teaching students.

"One cannot help being very anxious about the fact that the functions of health centres differ from area to area. No one seems to have defined what the total responsibility should be".