

SYMPOSIUM ON HÆMODYNAMICS IN PREGNANCY

V. HÆMODYNAMICS IN PREGNANCY

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My contribution to to-night's business is to make a short survey of the hæmodynamics in normal pregnancy. I would ask you to forgive me if my remarks are somewhat synoptic, but time would not permit me to deal with anything more than the barest facts.

THE CARDIAC OUTPUT IN PREGNANCY

It has long been suspected that the heart was in some way taxed during pregnancy, and as far back as 1871 Dr James Young of Edinburgh pointed out that the physical burden of pregnancy must necessarily lead to an increase in the work of the heart due specifically, he thought, to the increased work required of the muscles of locomotion. Half a century was to pass before this belief could be proved quantitatively. To-night Miss Hamilton has briefly reviewed the past work in this field and has shown that the pregnant woman expels at the period of maximum output some 25 per cent. more blood than in the resting state. Although this increase is somewhat less than that recorded by other investigators using different methods, yet it is an increase of no mean order and one which might prove a formidable burden to the damaged heart. We should perhaps note that these values refer only to the output at complete rest, and there is some evidence that a pregnant woman is uneconomical in her use of oxygen, and to perform a given piece of activity much more work is required from the heart than in the non-pregnant state. This increase in the cardiac output in pregnancy is one of the most fundamental points in the physiology of the circulation in pregnancy, and the distribution of this increased output to the various tissues must be analysed, and we shall return to this point later.

THE BLOOD VOLUME IN PREGNANCY

Miss White has pointed out to us that the increase in the total blood volume at term is something of the order of 25 to 30 per cent. This point has now been very thoroughly investigated and in so far as the method is accurate, we can have little doubt that this order of increase does occur but that the curve does not correspond to that of the cardiac output. A terminal fall in blood volume does not occur

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and Miss White has shown us that the return to normal occurs relatively slowly during the puerperium. We are not specifically concerned with tissue fluid metabolism to-night, but we are all most interested in Miss White's quantitative measurements of the changes in limb volume during normal and abnormal pregnancy. It has long been known that considerable water retention could occur in the limb without visible œdema being apparent, and it has been of great interest to find that this could amount to as much as 6 per cent. before œdema was, in fact, apparent.

The heart, then, expels more blood during pregnancy and the total amount of fluid with which it has to deal is similarly increased.

THE RATE OF THE CIRCULATION

These two facts might well mean that the whole circulatory rate might be speeded up—the blood being moved around faster. Comparatively few studies on the rate of the circulation have been made and the results do not appear to be entirely in agreement. Klee (1924), using the fluorescein method (arm to eye), found that the circulation rate was somewhat slower in pregnant than in non-pregnant women, while Spitzer (1933) found little or no change using the decholin method (arm to tongue). Cohen and Thomson (1939) carried out studies on this point. Generally speaking, they found that the arm to carotid circulation speed was within normal limits but there was some speeding-up of the circulation during the period seventeen to thirty-six weeks with a return to normal during the last four weeks of pregnancy. Wright (1949), using a radio-active salt, has shown that the rate of the venous blood flow in the legs is considerably retarded when determined during the first stage of labour and then rapidly returns to normal during the puerperium. The venous circulation in the lower limbs is, of course, considerably modified by the effect of gravity and the presence of the pregnant uterus. If we exclude the femoro-saphenous system, it does not seem that there is any great change in the speed of the circulation.

BLOOD VISCOSITY IN PREGNANCY

It has been repeatedly stated that the blood viscosity is lowered during pregnancy. If this in fact was true, it would be of very great importance, for a slight reduction in the viscousness of the blood would afford considerable relief to the heart. Yet when we examine the evidence for this belief, it is not too convincing. In fact, as far as I can discover, only one observer has made any direct measurements *in vivo*. Pellissier (1912), using the Hess viscometer, showed that some reduction in viscosity occurred. Cohen and Thomson (1936) simply calculated the viscosity from a formula derived from the hæmatocrit. They found that there was a progressive slight reduction in the viscosity of the blood, which was at lowest between the thirty-third and the thirty-sixth weeks.

We thought it prudent to re-examine this question and carried out a "pilot" experiment on a group of 10 normal women at the thirtieth week of pregnancy. Using the Ostwald viscometer, we found that if the relative viscosity of the blood in the normal woman be 5, then at the thirty-sixth week of pregnancy it is about 4.6 to 4.7—a very definite decrease. At any rate, we satisfied ourselves that there was a *prima facie* case for further investigation. The viscosity of the blood is a complex matter and it is necessary to examine not only the viscosity of whole blood, which is of importance in large vessels, but also of the plasma which is of greater importance in the smaller vessels. It is probably fair to conclude that there is some fall in the viscosity of the blood during pregnancy, but the matter requires further investigation.

THE PULSE RATE IN PREGNANCY

It is a curious fact that few observations on this point exist. Hare and Karn (1924) gave considerable attention to this point when they were investigating the blood pressure in normal pregnancy. In general they could not show any difference between the pulse rate of pregnant and non-pregnant women. Cohen and Thomson noted that the pulse rate in 37 normal pregnant women was 80.6, and that this dropped to 70 in the puerperium. Burwell (1938) found that in a small group of women, meticulously studied, the pulse rate during late pregnancy was 86 to 92, and this dropped to 75 during the puerperium. Miss Hamilton and Miss Burt have been able to give me some data from patients they have been investigating, and Miss Hamilton's figures are of interest in that all her patients were under basal and not merely resting conditions. Table I summarises the data available.

TABLE I
Pulse Rate in Pregnancy

	Non-pregnant.	Pregnant.	Puerperium.
Hare and Karn	83	84-87	...
Cohen and Thomson	80	70
Burwell <i>et al.</i>	86-92	75
Miss Hamilton	68 (basal)	78-82	...
Miss Burt	64	82	71

There seems, therefore, to be some evidence that there is a quickening of the heart during pregnancy and that this is greatest at the time of maximum cardiac output. More data, however, are required on the pulse rate in the truly basal state. Burwell makes the rather surprising statement that following cæsarean section the pulse rate immediately drops by ten beats. I was very surprised at this statement, and Dr J. D. Bourke obliged me by analysing his own anæsthetic records. In point of fact, he found that following elective cæsarean section the heart may quicken, may remain unaltered or slow.

THE ARTERIAL BLOOD PRESSURE IN PREGNANCY

Robinson and Brucer (1934) regarded the normal range of blood pressure in the normal woman as being between the range of 90 to 120 mm.Hg. systolic and 60 to 80 diastolic. Accordingly, many obstetricians now regard the maximum normal pressure in pregnancy as being 120/80, and I need not remind you that F. J. Browne and Chesley, whose knowledge of hypertension in pregnancy is unrivalled, both agree on this point. Robinson and Brucer's figures have not gone unchallenged, and some physicians and statisticians have objected to their sampling. Some obstetricians feel that the figure 120/80 is too stringent a maximum but all are perfectly agreed that any figure over 140/90 constitutes an abnormally high reading.

There are few recent studies on the normal blood pressure in pregnancy. Hare and Karn's exhaustive studies on this question disproved the older belief that there was a tendency to higher pressures in pregnancy. Later, Dieckman confirmed this. Hare and Karn appear to have been the first to show that during mid-pregnancy there was a tendency to low pressures and a drop of 10 mm.Hg. in both systolic and diastolic readings was not uncommon. This tendency to low readings—the so-called "mid-pregnancy drop"—does not occur in all individuals but can be quite striking. It is observed in the hypertensive patient in perhaps a third of cases. Whether or not there is a tendency to slightly increased blood pressures in the last three to four weeks of pregnancy remains unproved, but it is commonly observed in women who appear to be free from any taint of toxæmia.

We can, therefore, summarise the position as follows. During pregnancy the blood pressure does not alter greatly from normal except that there is a tendency to lowered pressures during mid-pregnancy. The question of a slight terminal rise remains open.

THE VENOUS PRESSURE

The older cardiologists and even Sir James McKenzie himself had often suspected that there was an increased jugular pressure during pregnancy, for the jugular vein can often be seen to be over full and pulsations noted. Considerable discussion on this point has taken place but the introduction of the cardiac catheter technique has enabled accurate measurements of intra-auricular pressure to be made. Miss Hamilton has shown that the right intra-auricular pressure is within the same range as the non-pregnant woman, namely—2.6 cms. of water below the sternal angle. We have as yet no data on the various pressures in the inferior vena cava, although the pressures in this vessel might be expected to show somewhat variable results depending on the weight and size of the uterus and possibly on parity.

Several studies on the venous pressures in the arms have been made, and MacLennan's fine study of the cubital venous pressures in 255 subjects would appear to show quite conclusively that there is no

increase in the venous pressure in this situation. On the other hand, and not unexpectedly, there was a steady rise in the femoral venous pressure which reached a height of 24.37 cms. H₂O by term in the supine patient. With the patient standing, the femoral venous pressure may reach a figure equivalent to 120 cms. of water. MacLennan's studies on the femoral venous pressures during cæsarean section are of great interest. When the uterus is opened and the liquor gushes out, there is a fall in pressure which becomes precipitate at the removal of the foetus. Removal of the placenta was associated with only a negligible further fall. Femoral venous pressures of the same order as those of pregnancy are found in patients with tumours of the ovaries and uterus.

CHANGES IN THE CAPILLARIES

Capillary microscopy shows a tendency to capillary dilatation in the nail folds and there is almost certainly a rise in the venous capillary pressure in the legs. There seems to be a tendency to capillary dilatation during pregnancy and many women note the presence of little distended vessels over the malar region during pregnancy. Very often these "pregnancy spiders," as Dester terms them, do not disappear and remain as permanent evidence of fecundity.

These remarks conclude our review of the general circulatory changes during pregnancy and we must now turn to study the blood flow to individual organs.

HEPATIC BLOOD FLOW

A catheter can be passed through the heart into the right hepatic vein which opens into the inferior vena cava just below the auricle. It is possible, therefore, to inject a dye which is removed by the liver and thus calculate the blood flow through that organ. Bradley's method has now been widely used and has been applied to the pregnant woman. The blood flow through the liver gives us a picture of the flow through the whole splanchnic area. Munnell (1947) and Taylor have investigated this question and found that the blood flow through the liver is of the same order in both pregnant and non-pregnant women—namely about 1500 c.c. per minute. The point to note is that the liver does not share in the increased cardiac output of pregnancy. Although not strictly germane to our discussion, we might note that greatly increased hepatic flows were noted in pre-eclampsia.

RENAL BLOOD FLOW

We are not concerned to-night with the minutiae of renal function but rather with the blood flow to the organ in pregnancy. That there is a "strain" on the kidneys during pregnancy is, curiously enough, a belief widely held, but the evidence on which this is based is scanty. However, Smith has introduced methods whereby both tubular and glomerular function can be analysed. The methods of inulin and diodrast or para-amino-hippuric acid have been profitably used and many

new terms are now in use. The normal renal blood flow through the healthy woman's kidneys is about 850-950 c.c. per minute and Table II gives the results found during pregnancy and the post-partum period.

TABLE II

Renal Blood Flow

	Ante-partum.	Post-partum.
Chesley <i>et al.</i>	850 c.c.	...
Dill <i>et al.</i>	950 c.c.	979 c.c.
Wellen, Welsh and Taylor	970 c.c.	858 c.c.

Again the point to note is that the kidney, like the liver, does not share in the increased output of the heart.

CEREBRAL BLOOD FLOW

The technique for measuring the cerebral blood flow is not an easy one and so far I have not found any data on the cerebral blood flow in pregnancy. There is no evidence that it is increased or decreased, but such a study might be most valuable in the eclamptic patient. For the purposes of our calculations, we might suppose it to be unaltered.

PERIPHERAL BLOOD FLOW

Miss Burt has given us the results of her fascinating work on skin temperatures in normal pregnancy and has told you of our work on the blood flow through the forearm muscles. That at least under basal conditions there is a gradual increase in the blood flow of the hands and feet seems quite clear. The flow through the muscles also shows a definite increase. Here for the first time we meet a change from the non-pregnant state in that there is an increased blood flow through an organ.

As yet we know nothing of the blood flow through such important organs as the supra-renal glands, the thyroid, the lungs and the coronary vessels, yet changes might reasonably be supposed to exist and certainly the coronary vessels themselves must demand their share of the increased cardiac output.

THE UTERINE CIRCULATION

It is fashionable now to discuss disordered function in terms of anoxia—renal anoxia, hepatic anoxia and the like, and it is not surprising that placental anoxia is now suggested as a cause of pre-eclampsia. The fact that we know nothing of the blood flow through the uterus nor can we measure it does not daunt the theorist. Even if we could determine the total uterine blood flow, this might not necessarily reflect chorio-decidual flow. I have always insisted that a high myometrial flow might co-exist with a sluggish placental flow.

Can we say anything about the blood flow to the human pregnant uterus in terms of quantity? We have seen that at the period of maximum increase the heart is expelling about a litre more blood per minute than in the non-pregnant woman. We have seen that apart from the skin and possibly muscle, there is little evidence that any organ is sharing in this increased output. Suppose we allot a moiety of this increased output to the hands and muscles, certain endocrine glands and the breasts, it will be clear, then, that even at the period of maximum output, the uterus must be receiving considerably less than one litre a minute; and if it be that the cardiac output falls considerably during the last four weeks of pregnancy, it will follow that the flow to the uterus will be considerably less. Beyond this I don't think it legitimate to speculate.

Foiled in any attempt at any direct measurement of the blood flow through the uterus, we wondered if the measurement of the oxygen in the venous blood leaving the uterus might prove of interest, for if blood were passing through the uterus at an increased rate, the venous blood might be brighter. Or, alternatively, if the placenta were diseased, it might extract less oxygen from the arterial blood and thus cause the venous blood to become brighter. We have obtained samples of both choriodecidual blood and uterine venous blood in several women subjected to cæsarean section. What Barcroft found in the rabbit is true for the pregnant woman: the uterine venous blood is almost black, *i.e.* the arterio-venous difference is considerable. Following retraction of the uterus, the venous blood becomes quite bright and the oxygen difference between uterine arterial and venous blood is low. The method of obtaining blood is quite easy and this analysis may possibly give us some useful data in the future. At present we are simply studying the normal differences, but in a few cases of severe toxæmia we have noted that the uterine venous blood was not so dark, hinting at a possible decrease in oxygen consumption by the placenta or a speeding up of the circulation.

THE MEANING OF THE HÆMODYNAMIC CHANGES IN PREGNANCY

The mature pregnant uterus can be regarded as an entirely new organ introduced into a woman's circulatory system, not only a new organ but one that is comparatively large and vascular and avid for oxygen. The introduction of such a circuit in an artificial circulation would immediately cause a fall in the pressure of the circuit. To avoid this, one would have to increase the output of the pump either by making it work faster or by increasing the volume ejected at each stroke. We can see, therefore, that in the pregnant woman this difficulty is overcome by the increase in the cardiac output and the blood volume. It is easy to explain why there must be an increase in the cardiac output if the blood pressure is to remain normal, but this does not help us to know how it occurs.

Burwell has suggested that not only does the vascular pregnant uterus act as an area of decreased resistance but that this effect is exaggerated and that in fact the chorio-decidual area acts like an arterio-venous aneurysm or shunt. The parallelism between the hæmodynamic changes in an arterio-venous aneurysm of large size and those of pregnancy is indeed a close one—the increased cardiac output, the increased blood volume and so on are common to both. Two observations would seem to throw doubt on the chorio-decidual space acting in this way, however. Firstly, a radio-opaque substance injected into the aorta can be seen to remain in the placenta for a few seconds longer than in the other parts of the uterus, and Hartnell has shown this as early as the twentieth week. In other words, the older classical view that the placental circulation seems to be sluggish appears more likely to be true than the idea that there is an abnormally quick passage of blood through this area. Secondly, our preliminary studies on the oxygen content of the uterine venous blood do not support the shunt idea. The venous blood in an A/V aneurysm contains, of course, a higher quantity of oxygen than normal. We have found that this is not true in uterine venous blood. Let us say, then, that although it is agreed that the pregnant uterus is an area of decreased resistance, yet it is not possible to say that this effect is entirely or largely a placental one.

That some of the effects noted in the circulation might be due to an endocrine substance is more than likely. For instance, how far is the thyroid gland involved in the production of the changes noted? Mild thyrotoxicosis is quite common in pregnancy but in normal pregnancy the increased pulse pressure, tachycardia and so on are not present. Curiously enough, the serum precipitable iodine is raised quite early in pregnancy at some considerable time before the basal metabolic rate rises. Miss Burt has told us of one particularly interesting observation to-night, and that is that the insensitivity to cold noted in the hands of the pregnant woman persists well into the puerperium—an effect which can scarcely be due to the sex steroids or the gonadotrophins. The relation of the thyroid gland to pregnancy is well worthy of further study.

Mr President, Ladies and Gentlemen, I must now bring these remarks to a close. I hope I have been able to give you some idea of the changes occurring in the circulation during normal pregnancy. My colleagues have demonstrated how already they are finding deviations from this normal pattern in pregnancy toxæmia, and I have no doubt that these researches will lead to further elucidation of the hæmodynamic changes occurring in that condition.

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DISCUSSION

In the discussion which followed, *Dr Rae Gilchrist* stressed the importance of the fundamental processes which lead to increase in blood volume, cardiac output, cardiac rate, skin temperature and muscle blood flow in the healthy pregnant woman, and wondered what might constitute the first step in the process. Commenting on the drop in cardiac output during the last four weeks whilst the increase in blood volume persisted, he considered that this observation refuted the view of Burwell that such changes were in the nature of an arteriovenous fistula. Increase in blood volume is related to a primary sodium retention and possibly some endocrine factor formed the basis of the fundamental changes. *Dr Gilchrist* considered that the present tendency to perform cæsarean section in the presence of a failing heart three to four weeks before term was physiologically wrong in view of the evidence that cardiac output reached its maximum at the thirty-sixth week. In such cases it would be wiser to wait for some weeks during which time the cardiac output would fall. *Dr Gilchrist* pointed out the difficulty in distinguishing between the physiological and pathological, with particular reference to borderland cases of congestive heart failure in which the clinical signs might denote either an advanced degree of physiological change or pathological change. He considered that, when the fundamental problems of hypertension and toxæmia had been solved, the knowledge gained would be of great therapeutic value when applied to the study of heart failure. Referring to the increase in cardiac work, *Dr Gilchrist* pointed out that there was no evidence of cardiac hypertrophy from either experimental, clinical or autopsy studies and believed that the results were achieved by more complete contraction without structural change.

Professor Gaddum and *Drs Hill, Turner, Hewitt* and *Fahmy* also took part in the discussion.