Acta Paediatrica Academiae Scientiarum Hungaricae, Vol. 17 (1), pp. 1–8 (1976)

Is viviparity the best means of reproduction?

By

F. E. Hytten, M.D., Ph.D., F.R.C.O.G.

MRC Reproduction and Growth Unit, Princess Mary Maternity Hospital,
Newcastle upon Tyne, England

Received June 27, 1975

Successful reproduction in the context of evolution demands no more than perpetuation of the species, but an ideal system of reproduction should also aim for high efficiency.

Two basic systems have predominated: egg laying, and viviparity with placental attachment of the embryo to the mother. Egg-laying is inefficient in allowing huge losses and greatly limits the size of the newborn, although it has the advantage of causing little physiological upheaval to the mother. Viviparity, on the other hand, allows the growth of a much larger fetus, offers great protection and is highly efficient. Its major disadvantage is the enormous disturbance of the mother's physiology in the interests of ensuring that the fetus will not be rejected immunologically and that a continuous supply of nutrients can be provided and waste products removed.

Only the marsupial seems to have achieved a sensible compromise by producing the young at a very early stage when it is living as an egg embryo without the need for placentation, and then giving it continuous nourishment and great protection by milk feeding in an external pouch.

In any system of reproduction the basic requirement is to produce young sufficiently large and mature for independent existence, and so to maintain the species. For mammals that size appears to be determined by a natural law (Fig. 1) which relates the total weight of the offspring of a pregnancy to the weight of the mother over a ten million fold range from a bat weighing less than 5 g to a whale weighing over 50 000 kg [7].

On the basis of that law the appropriate weight for the independent existence of a human newborn infant whose mother has a body weight of 55 kg is about 3.5 kg, and a weight between 3.5 and 4.0 kg is, in most societies, consistent with minimum infant mortality [5] and might therefore be accepted as the optimum.

The design of a reproductive system for man therefore resolves itself into the question of how best to produce a viable 3.5 kg infant, "best" in the context of evolutionary pressures implying greatest efficiency and fewest losses. The problem is basically nutritional, the acquisition by the mother of enough nutrients of the right kind to build the fetus, and their transport to the site of building. And at the risk of still further oversimplification it can be said that Nature has, in general, adopted two alternative reproductive pathways: egg-laying and viviparity.

Both systems have major advan-

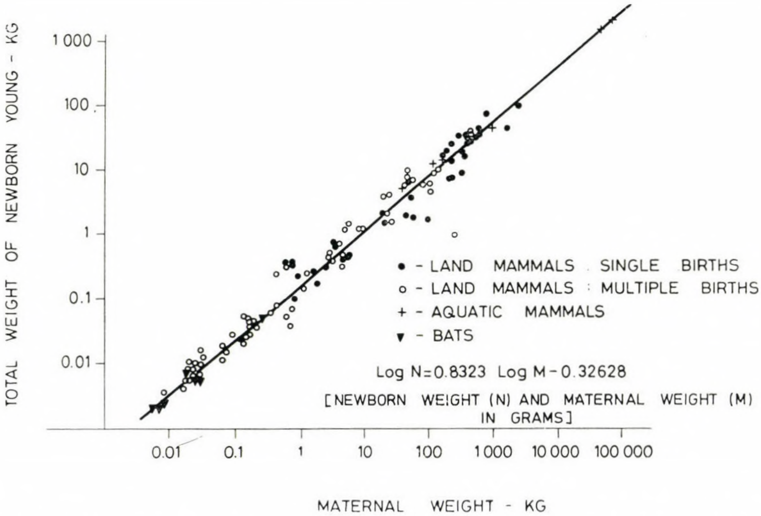

FIG. 1. The relationship between maternal weight and total weight of the newborn young in 114 mammalian species [7]

tages and disadvantages. In egg-laying there is the nutritional advantage that the nutrients needed for the construction of the fetus can be accumulated at a rate appropriate to the mother's nutritional circumstances; there is no need, as there is with viviparity, to ensure continuously a sufficient daily supply to the fetus of a range of specific nutrients.

There is the further advantage that once the egg is laid, physiological demands on the mother are negligible. But egg-laying has two major disadvantages. First, the egg is, in general, poorly protected, it is vulnerable to temperature changes and to structural damage so that losses in nature are usually high and the process is inefficient. Second, there are stringent practical limitations on size. It can be calculated that if nutrients were to be provided in an egg for the growth and development of a 3.5 kg young, the egg would have to be between 1.5 and 2 m in diameter, a size which would pose singular problems for the mother both of pelvic architecture and protective incubation, and would require for stability an egg-shell of 1—2 cm thickness which would be a particular problem for the young when the time came to emerge.

For our 3.5 kg young, viviparity has great advantages. Compared to the need to save up nutrients for an egg, the large quantity required can be more conveniently dispensed on a day to day basis; the protection of the developing young is considerable and limitation of size is imposed only by the size of the maternal abdomen.

Since the fundamental purposes of reproduction are only to maintain the species, the advantages outlined above are advantageous primarily to the fetus and the mother may see them in a rather different light. For example the convenience of being able to acquire nutrient needs from moment to moment works well for both mother and fetus when conditions are favourable, but faced with an acute shortage the fetus will attempt to ensure its own continuous supply if need be at the life-threatening expense of the maternal economy. And the comfort and protection enjoyed by the fetus from its position in the maternal abdomen may be far from comfortable for the mother, both mechanically and in the widespread physiological adaptations she must make to serve the fetal needs.

To begin with, elaborate arrangements must be made for the mother to tolerate the fetus, as a homograft, for 40 weeks and it is only recently that the scale and ubiquity of the physiological changes made by the pregnant woman have been appreciated; every physiological system is modified and the resulting metabolic chaos is a widespread cause of diagnostic confusion.

Three examples of adaptation will suffice to show the cavalier fashion in which the fetus treats his mother by reaching out with hormones to alter her central control mechanisms. All are probably brought about by progesterone acting in the hypothalamus and they illustrate a range of effects, and a range of subsequent complications for the mother.

The first of these appears to cause the mother no problem at all: that is the resetting of her "thermostat" by which her body temperature is raised by some 0.5°C [1], a change which appears to be a genuine change in the set point of the thermoregulatory centre [3].

The second adaptation is more complex: the readjustment of the mother's energy balance. The pregnant woman gains much more weight than can be accounted for by the product of conception and in the growth of specific organs of reproduction such as the uterus and the breasts. The average healthy woman eating to appetite will gain about 12.5 kg; of that, no more than half is due to the uterus and its contents, another quarter is due to growth of the breasts and the accumulation of blood and tissue fluid by the mother, and the final quarter, about 3.5 kg, is otherwise unaccounted for (Fig. 2). Since there is no water associated with the 3.5 kg [6], there can be no question of it representing, as was once believed [9], a protein store. It is depot fat stored mostly in the subcutaneous tissues of the trunk and thighs. The storage of fat on this scale is otherwise unknown in healthy adult life and it seems reasonable on teleological grounds to regard it as an anticipatory energy buffer, amounting to more than 30,000 kcal (120 MJ) laid down in the first two thirds of pregnancy against possible later needs; it is analogous to similar storage by mammals before hibernation and birds before migration. An increased energy reserve in maternal fat depots may not be necessary in the undemanding conditions of modern urban civilization but it could be of great impor-

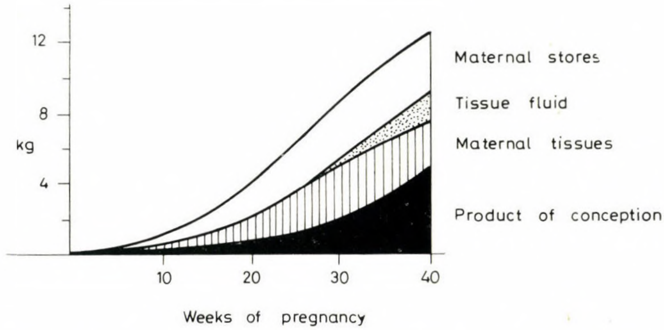

FIG. 2. The components of weight gained by the average healthy woman in pregnancy

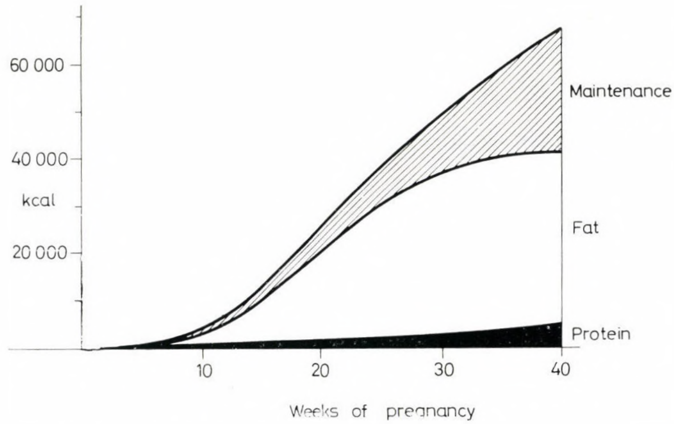

FIG. 3. The cumulative energy cost of pregnancy

tance to physically active women who are liable to undergo periods of nutritional deprivation. Such periods must have been common when mammalian reproduction was evolving, and are still common in many developing countries.

The energy requirements specific to pregnancy are summarized in Fig. 3. "Capital gains" of fat and protein amount to some 40,000 kcal (160 MJ), 4 kg of fat including that in the fetus, and about 1 kg of protein in the product of conception and enlarged maternal organs of reproduction. To that must be added the "running costs" incurred by the metabolism of the new tissues and extra maternal cardiac, respiratory and renal work [5].

It can be seen from Fig. 3 that in the first two thirds of pregnancy tissue formation, almost entirely fat, predominates, while during the final third running costs are increasing most rapidly, and that the energy stored in fat could, if need be, fully subsidize the inescapable maintenance requirements of late pregnancy. If the energy needs of pregnancy do not require subsidy, then the much greater energy demands of lactation could be assisted.

The consequence of the early pregnancy fat storage is that the energy needs of pregnancy are spread fairly evenly over most of pregnancy, the slope of the top line in Fig. 3 representing some 350 kcal (1.4 MJ) per day during the last two thirds of pregnancy.

Theoretically, the fat could be laid down simply by altering the mother's appetite-satiety centres so that she ate more food, but there is reason to think that a more fundamental alteration of energy balance has been made. Progesterone probably resets the so-called "lipostat" causing the mother to increase her store of body fat which she can do by either eating more, or expending less energy, or both. The evidence is that both contribute to the positive energy balance in human pregnancy; the mother undoubtedly eats more on average, and also saves energy expenditure both by resting more and by performing her daily tasks with increased economy of effort. In addition, a fall in the circulating concentration of free thyroid hormone may cause a general lowering of maternal metabolism.

Compared to the simple readjustment of the maternal thermostat, in this second example of fetal interference with maternal control mechanisms the fetus accomplishes its object of establishing an energy buffer against possible privation with rather more inconvenience to the mother, not merely in the spreading hips which make her pre-pregnancy clothes uncomfortably tight after delivery but in the obtrusive appetite and the lethargy of early pregnancy.

In the third example to be considered the fetus also arranges a simple change in maternal homeostasis for his own comfort, but the consequences for the mother are profound and far-reaching.

The fetus ' resets" the mother's respiratory centres, so that she grossly overbreathes from early pregnancy to reduce her P_ACO_2 from about 40 mm Hg to 30 mm Hg or even less. In addition to the resetting, the respiratory centres become more sensitive so that whereas before pregnancy a rise in P_ACO_2 of 1 mm will cause an increased ventilation of 1 or 2 litres per minute, the same rise in pregnancy leads to an increased ventilation of about 6 litres per minute [8, 11] (Fig. 4). The reduced pCO_2 which the mother is guarding so assiduously makes teleological sense since it helps the fetus to dispose of CO_2 which may be important because the newborn infant, and presumably also the fetus, is more sensitive than the adult to CO_2 [2].

To lower the PCO_2 by overbreathing is a relatively simple physiological operation, even if many women suffer the discomfort of dyspnoea as a result [5], but it cannot be achieved in isolation. First, if the blood pH is to be preserved, which it is [13], then the plasma concentration of bicarbonate must be lowered parallel with the pCO_2 and if bicarbon-

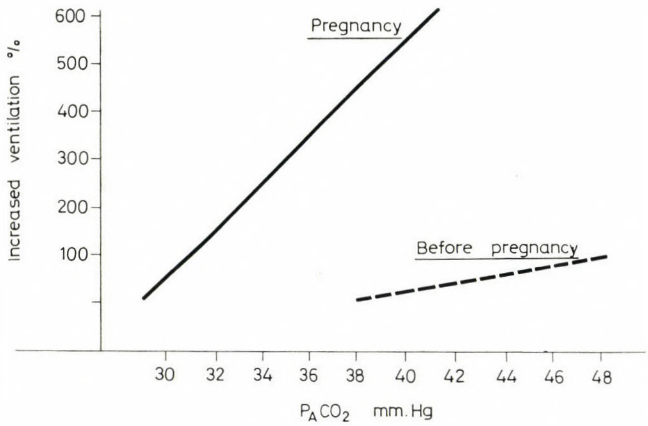

FIG. 4. The effect of pregnancy on P_ACO_2: The resting level is reduced from about 38 mm Hg to below 30 mm Hg and the sensitivity to a raised P_ACO_2 is increased

ate goes, then so does an equivalent amount of sodium, and this, together with a number of other changes in blood composition, leads to a considerable fall in plasma osmolality [12]. The body has what is recognized as a very sensitive control mechanism for maintaining plasma osmolality and a fall of 2%, or about 6 mOsm/kg below the normally preserved level, which may occur briefly after a fairly large water load, stops the secretion of vasopressin (ADH) and allows maximum diuresis [10].

In early pregnancy, largely because of the sodium loss, plasma osmolality drops abruptly by about 10 mOsm/kg — more than 3% (Fig. 5). In other words, the pregnant woman might be expected to cease the secretion of vasopressin and be in a state of continuous diuresis. That she is not suggests that the osmoreceptors have had also to be reset to accept and preserve a new low level of osmolality in the same way as the respiratory centres are reset to accept a new low level of pCO_2. The chain of events is briefly summarized in Fig. 6.

If this secondary adjustment has a lag, and I believe it has, then transitory signs of diabetes insipidus may occur. There is evidence that they do: polyuria is common and there is an almost universal complaint of excessive thirst in early pregnancy. A lack of vasopressin might explain some of the other symptoms of early pregnancy attributable to reduced smooth muscle tone, for example a low diastolic blood pressure, nausea, constipation and dilatation of the ureters. After delivery an equivalent lag in the recovery of this adjustment would mean a rising plasma osmolality with low set osmoreceptors and, therefore, an increased secretion of vasopressin leading to antidiuresis and water retention — precisely what happens in the first few days of the puerperium [4]. Whether the lowered plasma sodium has any other effects on renal function is uncertain, but one of the earliest features of pregnancy is an

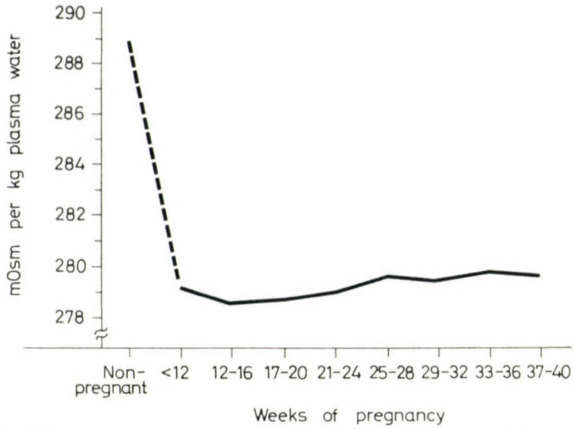

FIG. 5. The effect of pregnancy on plasma osmolality [12]

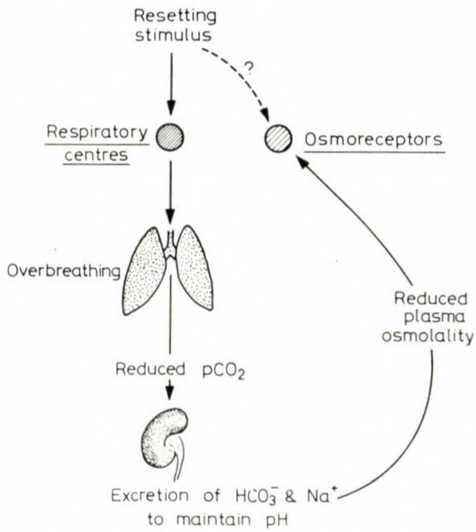

FIG. 6. The possible chain of events which follows the "resetting" of the respiratory centres in pregnancy

enormously increased glomerular filtration rate and perhaps other changes of renal function which permit the extraordinary losses of nutrients such as amino acids and the water soluble vitamins.

Before pregnancy the major preoccupation of the normal body is to maintain internal environmental conditions which are presumably best suited to the functioning of the body in the external environment in which it finds itself. In pregnancy, the same body, living in the same external environment, is subject to a radically different internal environment. If the non-pregnant arrangements are best suited to the functioning of the body, then it follows that a completely changed arrangement cannot equally be best suited to the functioning of the body. We can only assume that the fetus is engineering the changes with its own hormones in the interests of providing what will be the best environment for itself, for example, the provision of adequate food reserves for its final stages of growth and the provision of a favourable carbon dioxide transport system; it is surprising that the average woman tolerates this extraordinary over-riding of her own controls with so little visible distress.

Nevertheless these few examples are enough to show that she is being impelled to make considerable physiological sacrifices to ensure the success of viviparous reproduction.

Ideally, a system of reproduction would evolve which had the advantages of both egg-laying and viviparity without their disadvantages. Such a system already exists: marsupials such as the kangaroo have an intrauterine gestation short enough to avoid the necessity of implantation, the consequent problems of transplantation immunity and the huge programme of physiological disruption which follows implantation. The red kangaroo, which is almost as big as an adult woman, has an embryo which is born when it is only a few millimetres long, so that the mother undergoes no mechanical stress during birth, after which the embryo migrates to an external abdominal pouch where it fixes to a nipple. For the rest of the "pregnancy" the young is as well protected as an intrauterine young, it is fed on a moment-to-moment basis by milk and its subsequent separation from the mother can be undertaken gradually to the maximum advantage of both mother and infant.

There are problems to be overcome, not the least of which are arranging for an embryo of a few millimetres long to have lungs mature enough to breathe air and to be able to climb vertically through perhaps 20 cm of fur using only limb buds, but the kangaroo has achieved this and enjoys a fetal mortality comparable to that of man.

Prof. F. E. Hytten
Clinical Research Centre
Watford Rd., Harrow, HA1 3UJ,
Middlesex, England

References

1. Buxton, C. L., Atkinson, W. B.: J. clin. Endocr. **8**, 544 (1948)
2. Cross, K. W., Hooper, J. M. D., Oppe, T. E.: J. Physiol. (Lond.) **119,** 11 (1953)
3. Cunningham, D. J., Cabanac, M.: J. Physiol. (Paris) **63,** 236 (1971)
4. Dennis, K. J.: J. Reprod. Fertil. **10,** 292 (1965)
5. Hytten, F. E., Leitch, I.: The Physiology of Human Pregnancy, 2nd Ed. Blackwell Scientific Publications, Oxford 1971
6. Hytten, F. E., Thomson, A. M., Taggart, N.: J. Obstet. Gynaec. Brit. Cwlth **73,** 553 (1966)
7. Leitch, I., Hytten, F. E., Billewicz, W. Z.: Proc. zool. Soc. **133,** 11 (1959)
8. Lyons, H. A., Antonio, R.: Trans. Ass. Amer. Phycns **72,** 173 (1959)
9. Macy, I. G., Hunscher, H. A.: Amer. Obstet. Gynec. **27,** 878 (1934)
10. O'Connor, W. J.: Renal Function. Edward Arnold, London 1962
11. Prowse, C. M., Gaensler, E. A.: Anaesthesiology **26,** 381 (1965)
12. Robertson, E. G., Cheyne, G. A.: J. Obstet. Gynaec. Brit. Cwlth **79,** 769 (1972)
13. Seeds, A. E., Battaglia, F. C., Hellegers, A. E.: Amer. J. Obstet. Gynec. **88,** 1086 (1964)