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Fetal Heart Rate in Relation to Body Mass (41535)

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Abstract. In contrast to the inverse relation of heart rate to body mass in adult mammals, the heart rate of immature fetuses is unrelated to body mass and approximately constant among different species. With maturation, fetal heart rate decreases in a large mammal but tends to increase in a small mammal. These maturational changes reduce the difference between the heart rate of a term fetus and the heart rate which is "appropriate for body mass" as calculated by means of the allometric equation for adults. The comparative physiology of fetal heart rate supports the hypothesis that immature fetuses of small and large mammals have similar oxygen consumption rates per unit body mass.

The scaling of metabolic and circulatory functions to body mass is a fundamental problem of comparative physiology (1). In articles containing descriptions and theoretical discussions of this problem we have found no reference to the mammalian fetus, but for a suggestion by Kleiber (2) that fetal and maternal metabolic rates may be similar. Experimental data have shown, however, that the mass specific oxygen consumption rate of the ovine fetus is approximately twice that of the maternal organism at rest (3). Furthermore, observations in other species have suggested the hypothesis that fetal oxygen consumption per unit body mass tends to be constant in mammals ranging in size from guinea pig to horse (3). This constancy would be in marked contrast to the well-known fact (1) that in adult mammals the weight-specific metabolic rate is inversely related to body mass with an allometric exponent approximately equal to −0.25.

An interesting corollary of this hypothesis is that in a small mammal each fetus would represent a region of relatively low oxygen consumption within the maternal organism whereas in a large mammal the opposite is true. The ability of small mammals to carry a large fetal mass could find a partial explanation in these metabolic relationships (3). In searching for further evidence about the validity of the hypothesis we turned our attention to the relation between fetal heart rate and fetal body mass. If we accept as valid the experimental data indicating that fetuses with body mass differing by one or more orders of magnitude have similar oxygen consumption rates per unit body weight, then it is reasonable to assume that they should have similar cardiac outputs per unit body weight. Since the heart weight/body weight ratio is fairly constant among fetuses of different species (4–7) (Table I) we would expect also a similarity in fetal heart rates.

A related problem is the relationship of fetal heart rate to fetal body mass within the same species. The available information seems contradictory. A progressive decrease of fetal heart rate during gestation has been described in cattle (8), sheep (9), pigs (10), and humans (11), whereas a progressive increase (12) or no significant change (13) have been described in the rat and guinea pig. However, data unbiased by abnormal physiologic conditions and sufficiently detailed to allow an estimate of fetal mass are available in the human and ovine fetus only. The data in small mammals seemed to us the least reliable source of information because of the experimental conditions under which they were obtained and the conflicting evidence. Therefore we decided to measure the heart rate of the guinea pig fetus under normal physiologic conditions.

Materials and Methods. Guinea pigs were selected because they are docile and have been used extensively in studies of placental and fetal physiology. Initially we attempted to

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TABLE I. FETAL HEART WEIGHT/BODY WEIGHT RATIOS (R) IN DIFFERENT SPECIES[a]

	$R \times 100$	Reference
Rat	0.65	4
Guinea pig	0.52	Present study
Rhesus monkey	0.65	5
Pig	0.65	6
Sheep	0.64	Unpublished data
Human	0.65	7

[a] All data refer to fetuses close to term.

measure fetal heart rate by implanting electrodes on the fetal skin under sterile surgical conditions and recording the fetal electrocardiogram in the postoperative period. However, four of seven animals studied by this methodology aborted 3 days after surgery casting doubt on the validity of the results. For this reason the surgical approach was abandoned in favor of a noninvasive method of heart detection using a 9.1-MHz Doppler ultrasound transducer (Parks Electronics Lab., Beaverton, Ore.). The method gave reproducible results and had no adverse effect on the course of pregnancy. Animals accustomed to handling were used for the experiment. Each day the mother was held on a table in her normal sitting position and the transducer was applied to her flank which had been shaved and coated with an acoustic gel. The signal from the transducer was displayed on a recorder. Three animals were examined daily by this technique. In one, the heart rates of two fetuses were monitored by placing the transducer on both flanks. In two of the animals, maternal heart rate was also recorded.

Results. The mean heart rate of the seven fetuses studied by means of the invasive technique was 234 beats/min (range 206 to 291). In the group studied by means of the noninvasive method each guinea pig delivered at term a healthy litter. Two of the animals had four fetuses each, the other had five. The mean birth weight was 100.2 g ± 10.4 SD. The postpartum maternal weight ranged between 840 and 890 g. In two litters the heart rates of each newborn were recorded each day for the first 6 postnatal days. Figure 1 shows the results of the measurements by the noninvasive technique. Within the gestation range of 38 to 50 days the mean fetal heart rate was 212 ± 3 beats/min. From 50 days onward the fetal heart rate began to increase and attained a mean value of 259 ± 5 beats/min in the last 5 days before birth. Throughout the study period the fetal heart rate was less than the maternal heart rate. Following birth there was a sharp increase of heart rate to values ranging between 390 and 540 beats/min in the first 6 days of life.

Discussion. The heart rate/body mass relationship in the guinea pig fetus is presented in Fig. 2 and compared with the same relationship in the human, ovine, bovine, and equine fetus and in adult mammals. The fetal mass was estimated from growth curves except for the bovine fetus. The observations for the horse fetus were obtained by us by means of an ultrasound Doppler transducer in two Morgan horses close to term. It is apparent that the heart rate of an immature fetal guinea pig is virtually the same as the heart rate of an immature sheep fetus—despite an 80-fold discrepancy in body mass—and only 30% higher than the heart rate of a human fetus of the same mass. The relative constancy of fetal heart rate contrasts with the steep, inverse relation of heart rate to body mass of adults. It is this difference between the adult and the fetal organisms which is responsible for the paradoxical observation that in the small mammal fetal heart rate is less than ma-

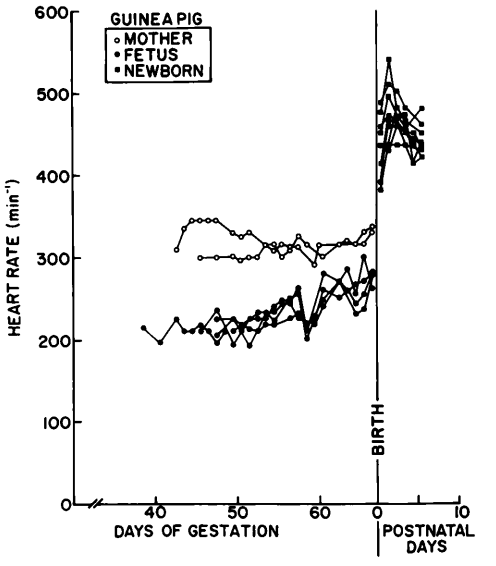

FIG. 1. Maternal, fetal, and neonatal heart rates in guinea pigs under normal physiologic conditions.

ternal heart rate. The size of the species, therefore, determines whether maternal heart rate is lower, equal, or higher than fetal heart rate.

Despite a basic interspecies similarity in the heart rate of immature fetuses there is an interesting discrepancy associated with fetal maturation. In the ovine, bovine, and human fetus, heart rate tends to decrease during gestation, but in the guinea pig there is an opposite trend. Although the data about the bovine fetus must be considered with caution because they were obtained with invasive techniques under acute experimental conditions, it is clear that the discrepancy between the guinea pig and the other fetuses is related to body mass at birth. If the adult heart rate/body mass relation is assumed to be an index of what the heart rate in a mammal well adapted to extrauterine life should be, it is obvious from an inspection of the data in Fig. 2 that the heart rate/body mass ratio in the immature fetus of a small mammal is well below the appropriate level for a free existence in the external environment, whereas the opposite is true for the immature fetus of a large mammal. Therefore, it is not surprising to find that in the guinea pig on the one hand and in the sheep and cow on the other, three species that produce mature newborns, the last days of intrauterine life are associated with opposite trends in heart rate changes. Despite the increase which brings the heart rate of a term guinea pig fetus to the 260 beats/min level, there is an additional large increase of heart rate in the first days of postnatal life. This behavior is in marked contrast to that of the human newborn, whose heart rate becomes somewhat slower than it was *in utero* (approximately 120 beats/min at 5 days of postnatal age) (14).

In conclusion, the heart rate of an immature fetus is unrelated to body mass. This conclusion is in agreement with the hypothesis that the weight-specific O_2 consumption rates of immature fetuses of different sizes are similar. As fetuses approach birth, heart rate and body mass become interrelated. The study of this relationship in different species indicates that it is a maturation process in preparation for extrauterine existence. Whether such maturation process is accompanied by changes in metabolic rate remains to be seen. The virtual independence of heart rate from body size in immature fetuses is probably an expression of the fact that the fetus *in utero* does not exchange heat through the body surface and has no gravitational loading—two conditions which have been assumed to play an important role in determining the relationship between metabolic rate and body mass in adult mammals (15).

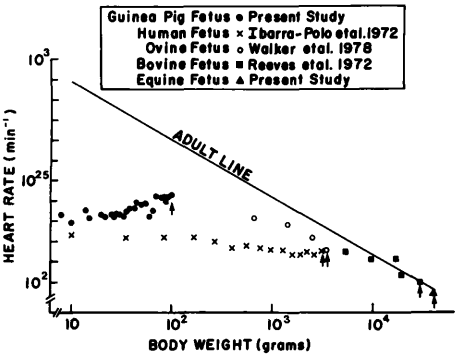

FIG. 2. Logarithmic plot of heart rate vs body weight in fetuses of different species. Each point represents the mean of two or more observations. With the exception of the bovine fetus, all observations were in conscious animals, under normal physiologic conditions. The line marked "ADULT" represents the allometric relation of heart rate to body mass in adult mammals (see Ref. (1)). The arrows indicate the heart rate/body weight relation shortly before labor.

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