STABILITY OF PARTIAL OXYGEN PRESSURE IN THE FETAL BRAIN TO CHANGES IN MATERNAL OXYGENATION

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UDC 616.831-008.922.1-053.1-02-07

KEY WORDS: fetus; brain; hypoxia; hyperoxia

The widespread use of oxygen therapy in perinatal medicine for various types of fetal hypoxia (asphyxia) necessitates an objective evaluation of the oxygen homeostasis of the developing fetus in utero. For this purpose, it is usual in clinical practice to record the partial pressure of oxygen (pO_2) only in superficial tissues (percutaneously, intradermally) of the presenting part of the fetus [5, 13]. It will be evident, however, that the most interesting course is to study the brain pO_2, for we know that most of the unfavorable consequences of disturbances of oxygenation of the development of the fetus are due to an inadequate oxygen supply to its cerebral structures. Data in the literature on investigation of the fetal brain pO_2 are sporadic [3].

The aim of this investigation was to study the time course of pO_2 in the fetal rat brain during inhalation of hypoxic and hyperoxic gas mixtures by the pregnant animals.

EXPERIMENTAL METHOD

Experiments were carried out on 86 anesthetized (urethane, 1 g/kg) pregnant (19th-21st day) rats and their fetuses (76). pO_2 was recorded by a polarographic method, using platinum (diameter 0.1 mm) and Ag—AgCl electrodes. An area of the wall of the uterine cornu corresponding to the position of the fetal head was sutured to the edges of an incision in the anterior abdominal wall. An incision (2-3 mm) was made in the wall of the uterus and in the membranes so that a small area of the fetal head was exposed (the whole fetus, surrounded by membranes and the uterus, remained in the abdominal cavity). A cathode was inserted into the brain to a depth of 2 mm through a burr hole, equal in diameter to the thickness of the electrode, ensuring its adequate fixation (the electrode was connected to the instrument by means of a thin, flexible wire). An Ag—AgCl disk was inserted into the abdominal cavity of the pregnant rat. Changes in maternal oxygenation were brought about by making the animal inhale gas mixtures with high (50%, 100%) and low (10%) oxygen concentrations in nitrogen for 10 min. Values of pO_2 of arterial blood (p_aO_2) of the pregnant rats and pO_2 of the amniotic fluid were measured on an AZIV-2 instrument immediately after samples were taken. The shift of pO_2 in the fetal brain was expressed as a percentage of the initial level [4]; in a separate series of experiments (41 fetuses) the absolute value of the brain pO_2 was found after preliminary calibration of the electrodes [1]. Series of experiments also were undertaken in which pO_2 was recorded in fetal muscle (7) and subcutaneous cellular tissue (9). The experimental results were processed by the usual statistical methods.

EXPERIMENTAL RESULTS

The pO_2 level in the fetal brain was 5.69 ± 0.42 hPa, much lower than in adult animals [1, 4]. The reason is that p_aO_2 of the intrauterine fetus is only 27-33 hPa [2, 8], i.e., 4-5 times less than in adults. This evidently reflects the comparatively low oxygen consumption of the fetal brain, whose energy is supplied mainly by anaerobic processes [6]. Low values of pO_2 in the fetal brain are also understandable on general biological grounds. We know that in the early stages of evolution, living systems developed at low values of the ambient partial oxygen pressure. Consequently, in the early stages of ontogeny, which are essentially the condensed repetition of phylogeny, a low tissue pO_2 level is normal.

Medical Institute, Orenburg. (Presented by Academician of the Academy of Medical Sciences of the USSR, V. N. Negovskii.) Translated from Byulleten' Éksperimental'noi Biologii i Meditsiny, Vol. 108, No. 7, pp. 12-14, July, 1989. Original article submitted June 22, 1988.

0007-4888/89/0007-0915$12.50

TABLE 1. Amplitude of pO_2 Changes in Fetal Brain and Comparison with p_aO_2 of Pregnant Rats and pO_2 of the Amniotic Fluid

Oxygen concentration inspired air, %	Changes in pO_2 in fetal brain, % of initial level		paO_1 of pregnant rats, hPa	pO_2 of amniotic fluid, hPa
	type II	type III		
21	100,0	100,0	104,0±0,9	43,9±2,4
50	88,6±1,4*	112,6±3,7*	265,0±3,3*	—
100	79,2±1,9*	115,8±2,6*	496,0±16,0*	46,7±3,2
10	113,6±1,9*	83,9±2,5*	62,9±2,7*	33,1±2,9*

Legend. *$p < 0.05$.

Three types of changes in pO_2 in the fetal brain were found during inhalation of hypoxic and hyperoxic gas mixtures by the pregnant rats (Table 1): type I) absence of reversible deviations of pO_2 (45% of observations); II) a reversible increase in pO_2 during hypoxia and decrease during hyperoxia (35% of observations); III) a reversible decrease in pO_2 during hypoxia and increase during hyperoxia (20% of observations). Essentially the amplitude of shifts in pO_2 of the fetal brain in response to changes in maternal oxygenation did not exceed 20% of the initial level. Since the basic values of pO_2 in the fetal brain were under 6 hPa, it can be concluded that deviations of pO_2 in it during exposure of the pregnant animals to hypoxia and hyperoxia did not exceed 2-3 hPa, i.e., they were exceedingly small. Considering that in 45% of observations no changes were found in pO_2 of the brain during intrauterine development of the fetus, the following conclusion can be accepted as well substantiated: pO_2 in the fetal brain is resistant to considerable changes (from 500 to 60 hPa) in maternal p_aO_2.

The absence of changes in pO_2 in the fetal brain in utero during inhalation of hypoxic and hyperoxic gas mixtures by pregnant rats may at first glance appear strange. However, the results do not contradict existing views on tissue oxygen kinetics during changes in oxygenation of the organism. Similar results (absence of changes in tissue pO_2 or changes opposite to those in p_aO_2) may also be observed in adult animals [1]. It has also been shown that during changes in maternal oxygenation, several parameters of oxygen homeostasis of the fetus either remain unchanged or change only very slightly, and this is particularly true of p_aO_2 of the fetus [15], pO_2 of the amniotic fluid [11], and pO_2 measured percutaneously in the presenting part of the fetal head [10, 13]. The results of the present experiments to determine pO_2 of the amniotic fluid (Table 1) also point to absence or only a small amplitude of changes in this parameter.

Constancy of pO_2 in the fetal brain is evidence that definite mechanisms of stabilization of the oxygen hemostasis of the cerebral structures of the fetus during intrauterine development exist in the mother–fetus system. The results of experiments during which pO_2 was recorded in the fetal muscle and subcutaneous cellular tissue suggest the possible location of these mechanisms. These experiments also revealed stability of pO_2 of the test tissues during changes in the level of maternal oxygenation. Consequently, constancy of pO_2 of the various fetal tissues is due, not to local (organ or tissue) mechanisms, but either to systemic changes taking place in the fetus during intrauterine development or to compensatory reactions of the pregnant animal (mainly of her hemodynamics). Although data on changes in systemic and regional parameters of the fetal hemodynamics in hypoxia and hyperoxia have been described in the literature [12, 14], we consider that these changes do not play a leading role in stabilizing the fetal brain pO_2. This view is supported by data published previously [7], according to which pO_2 in the neonatal rat brain undergoes regular and reversible changes during inhalation of gas mixtures with a raised and lowered oxygen concentration (moreover, the amplitude of the changes is much greater than that in adult rats).

The most probable mechanism of stabilization of oxygen hemostasis of the fetal brain is one of adaptive changes in the uterine blood flow in response to changes in p_aO_2 of the pregnant animal [3]. An essential role in the mechanism of this phenomenon may also be played by the placenta, structures of which utilize up to 50% of the oxygen supplied to the placenta–fetus system [9].

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