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Fetus to Newborn: The Perinatal Period

Curriculum Unit 82.07.08
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(figure available in print form)

Introduction:

"The most hazardous time in an infant's life is the perinatal period, the days immediately before and 28 days after birth. For those babies who survive, over seven decades of life may be anticipated." [1]

My unit concerns this critical perinatal time when the fetus, who is adapted to life inside its mother, must suddenly at birth be able to survive in a totally different environment. For nine months, the fetus has all its needs taken care of by the mother through the placenta: food and oxygen diffuse in and wastes move out, it is protected from many germs, kept warm and supplied with its own gymnastics studio in the amniotic fluid of the womb.

At the same time, all its organ systems are preparing for life outside the womb however, because it must be ready at birth to make an immediate switch-over to its new environment.

Consider all the things that have to take place when the umbilical cord is cut:

The neonate breathes air for the first time, forcing fluid out of its lungs.

It must close two shunts in its circulatory system so that blood will go to the lungs (instead of the placenta).

The immature liver starts excreting waste products, but not very efficiently,with the result that many newborns are jaundiced.

The neonate must keep warm in an environment that is much colder than its mother's body.

It must start producing its own antibodies to protect it from infection in a very germy world.

Its reflexes must be well enough developed to enable it to suck and swallow.

This unit on the perinatal period would be appropriate for biology, human physiology and advanced biology classes. (Much of it could also be used in middle school science classes.) It could be taught as a three to four week unit towards the end of the school year after students have studied the major body systems *or* parts of it could be used wherever applicable. The important thing to emphasize in either case is the contrast between fetal and adult adaptations to their two different environments.

The field of perinatology is so new that very little information has reached the level of high school textbooks yet, although there are almost daily newspaper articles such as, "Operation saves kidney of fetus" or "New test developed to find sickle cell anemia in fetuses". The information in this unit is a summary of what I learned from medical journals and books at the Yale Medical School Library (most of the references are later than 1970), and also from Dr. Maurice J. Mahoney's stimulating seminar, "Human Fetal Development" at the Yale Mew Haven Teachers Institute.

Many of the activities in the unit rely on materials and expertise supplied by Dr. Mahoney and his associate, Dr. Cara Smith, of the Department of Human Genetics at Yale. I am grateful for their generosity and enthusiasm.

Ultrasound photo of Third trimester fetus. Courtesy: B. Cherry
(figure available in print form)

The Placenta:

The placenta is a mystery organ. Few people have ever seen one and thus it is difficult to visualize its shape and attachment to the uterus. Because of this, my students prefer to talk about the umbilical cord (instead of the placenta) as the main organ of transmission between mother and fetus. This section is an attempt to restore the more complicated placenta to its rightful place. Much of my information comes from Beaconsfield (1980).

The placenta develops from the fertilized egg, therefore half its genes are from the father and it is a foreign entity that the mother's body should have a natural tendency to reject. But even though the placenta erodes its way into her uterine lining she does not reject it and scientists are not really sure why.

Two current hypotheses are these: The cells of the outer layer of the placenta do not produce antigens that the mother's lymphocytes would recognize as foreign, and also, the high level of hormones produced by the placenta suppress the activity of lymphocytes.

When mature the placenta is from eighteen to twenty inches in diameter and from two to three inches thick at the center where the cord is attached. Usually weighing one/sixth as much as the fetus at birth, it is smooth and shiny viewed from the fetal side, and rough and divided into many sections on the maternal side (see Beaconsfield, 1980 and Nilsson, 1977 for good pictures.)

The two umbilical arteries run into the placenta subdividing again and again until they end in capillaries inside thousands of little projections called villi (see diagram of placenta in Lesson Plan I at the end of unit.) These villi increase the surface area of the placenta to about ten square meters; a large surface area is very important wherever movement of molecules occurs across a membrane. The villi are bathed in a pool of approximately 150 cc of maternal blood which spurts out of spiral arteries in the uterine lining. There are no capillaries on the maternal side and the pool of blood simply drains back into open uterine veins. The supply of blood replenishes itself about three or four times every minute so that new supplies of food and oxygen are constantly moving into the fetal villi. From here the fetal capillaries join to finally form one large umbilical vein that returns to the fetus.

The placenta has an incredible range of functions: it is an organ of respiration, digestion, excretion and also an endocrine gland. It is important for students to understand its structure and functions, and also to know which substances it will transmit and how they affect the fetus. The following is a brief description of what the placenta can do:

Oxygen diffuses readily into the fetal villi since there is always a lower level in fetal blood. Aiding this movement is the fact that fetal erythrocytes (red blood cells) have a greater affinity for oxygen than maternal erythrocytes. Carbon dioxide diffuses in the opposite direction. (At this point you might ask your students to compare and contrast the placenta and lung. See the section on respiration.)

Glucose is the main energy source for the fetus and again it diffuses easily across to fetal capillaries because the gradient favors it. Amino acids move from mother to fetus also but since the fetal blood contains a higher concentration than the maternal blood there is probably active transport taking place across the membranes of the cells in the villi. (Active transport requires energy.) The placenta is very selective in the amino acids it takes in so that it can meet the specific needs of the growing fetus.

Pregnant teenagers are particularly susceptible to toxemia, a condition characterized by high blood pressure, the accumulation of fluid in the limbs and excess loss of protein in the urine. Because of this loss there may not be enough protein available for the fetus to build all its brain cells.

The placenta does not form a very efficient barrier against many drugs so that the fetus may be affected by alcohol, barbiturates, ether, morphine, heroin and many others (Burnhan, 1972). Both nicotine and carbon monoxide can reduce the size of the baby of a smoking mother. The immature liver of the fetus is unable to clear these drugs very fast and the effects may be profoundly damaging in the developing baby. (See Sherree Kassuba's unit in this volume).

Very few bacteria can cross the placenta (the spirochete of syphilis is an exception) but viral infections of the fetus do occur, such as rubella, herpes and CMV (cytomegalovirus), all with devastating results in early pregnancy. Luckily, IgG, a gamma globulin or antibody produced by the mother also crosses the placenta to give protection against many diseases. (The section on immunity describes how the mother protects her baby before and after birth if she is nursing.)

Excretion occurs in the opposite direction, from fetus to mother. The main substances are urea and uric acid which are excreted by the mother's kidneys, and also bilirubin, a breakdown product of red blood cells that can cause brain damage, but which is cleared by the mother's liver.

(figure available in print form)

The most fascinating function of the placenta is as an endocrine gland and its interaction with both fetus and mother to sustain a healthy pregnancy. The first hormone the placenta makes is HCG (Human Chorionic Gonadotropin), which can be detected in the mother's blood only eight days after ovulation (Niswander, 1976). HCG, which is the basis of urine Pregnancy tests, keeps the maternal ovary producing progesterone for the first two months until the placenta takes over. Progesterone is necessary to maintain pregnancy.

The placenta also produces a hormone with the incredible name of Human Chorionic Somatomammotropin (HCS), which as the name implies, makes the mother's breasts grow.

Another group of hormones are the estrogens,made jointly by the placenta and fetus during pregnancy. First the placenta makes progesterone which reaches the fetal adrenal glands by the umbilical vein. The fetus then makes a precursor of estrogen which is returned to the placenta where the final product of estrogen is finally produced. The fact that the fetus and placenta act together causes scientists to refer to them as the feto-placental unit. Estrogen which is necessary for growth of the uterus, breasts and other maternal organs is excreted in the mother's urine. Doctors use the levels as an indication of fetal and placental health—the higher the level, the better.

Activities:

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1. Lesson Plan 1 at the end of the unit. This is an activity to elucidate the structure and functions of the placenta.
2. Lesson Plan 11. A graph activity showing the effects of various environmental factors on the growth of the third trimester fetus.
3. Microscope slides of both placenta and umbilical cord are available at the Department of Human Genetics, courtesy of Dr. M.J. Mahoney and Dr. C. Smith. Ultrasound photos are also available showing the development of the fetus and organ systems. (contact me at 787-8758)
4. Dr. E. Crelin of the Yale Medical School has both embryological models and pictures which can be borrowed briefly. (again call me)
5. There is a transparency of the drawing "Placenta at Term" (previous page) at the Teachers Institute, 53 Wall St., call 436-3316. From "The Placenta" by Peter Beaconsfield, George Birdwood and Rebecca Beaconsfield. Copyright c August, 1980 by Scientific American, Inc. All rights reserved.
6. Also available at the Teachers Institute is the excellent filmstrip, "Life Before Birth" parts 1 and 2 with cassette. It is based on the Nilsson photos from " *A Child is Born* ."

The Respiratory System :

The respiratory system is crucial in determining whether a baby is mature enough to survive. The fetus is like a deep sea diver, immersed in fluid, and completely dependent on diffusion of maternal oxygen across the placenta. Its developing lungs which are filled with liquid are not needed during prenatal life and there is very little blood passing through them-enough only to keep them alive and developing.

However, even a nonfunctioning system has to be exercised in order to develop and it has been observed by ultrasound that the fetus makes breathing movements as early as four months (Niswander, 1976). Most pregnant women have also felt a rhythmic tapping which means that the fetus has hiccups. This probably helps to exercise the diaphragm and chest muscles so they will be functional at birth (Crelin, 1973).

The respiratory system starts developing at about five weeks in the embryo. The trachea forms first, then the bronchi and finally during the last trimester the tiny alveoli begin to develop . By twenty-six to twenty eight weeks, capillaries have reached out to the alveoli and the structural development of the lungs is practically complete.

One more thing is needed though before the baby can breathe on its own. At the sixth or seventh month, so-called Type II cells in the alveoli start producing a chemical called lecithin whose function is to keep the thin walls of the alveoli from collapsing after each breath. The reason they tend to cave in is because of surface tension pulling on the film of fluid which coats the inside of each alveolus. Lecithin is a surfactant (surface acting agent) which behaves like a detergent in reducing the surface tension of this fluid so our alveoli won't collapse when we exhale. It also reduces the muscular effort needed to draw air into our lungs.

(I would recommend obtaining the article from Scientific American called "The Lung of the Newborn Infant" by Mary Ellen Avery, Nai-San Wang and H. William Taeusch, Jr., April, 1973. It has good drawings and descriptions of the alveoli and Type II cells.)

When a baby is born, vaginal pressure squeezes much of the fluid out of its lungs and some air moves in to take its place. (The rest of the fluid is absorbed by the blood vessels and lymphatics in the lungs.) The baby's first few breaths are the hardest it will ever take in its life. They require a pressure that is ten to fifteen times that of later breaths because the baby has to inflate all of its alveoli at once (Avery et al., 1973).

With subsequent breaths forty percent of the air remains as residual air in the open alveoli and breathing becomes much easier. A premature baby who does not have enough surfactant in its lungs will continue to have to exert enormous effort with later breaths because all its alveoli will continue to collapse with each exhalation and must be totally opened again with each new breath.

This condition called Respiratory Distress Syndrome (RDS) is, of course, very serious; mortality rates may vary from thirty to sixty percent (Evans and Glass, 1976). It is also known as Hyaline Membrane Disease because serum and cell debris leak into the alveoli and bronchioles and coat them with a glassy covering which makes breathing even harder. The longer a baby can survive, the more of a chance it has of making surfactant although there is always the probability of brain damage due to lack of oxygen in the brain (hypoxia).

The best cure is prevention of premature birth if possible. Doctors now have a test which enables them to tell if the fetus's lungs are mature enough to breathe air. By amniocentesis they take a sample of amniotic fluid and test it for both the presence of lecithin and another chemical called sphingomyelin. If the L/S ratio is at least 2.0 it is a good indication that the lungs are producing enough lecithin for survival. If the ratio is lower, then everything possible is done to ensure that the mother will not give birth yet.

The respiratory system does not finish growing at birth in contrast, for instance, to the skeletal muscular system where all the fibers we will have as adults have been produced by the fourth fetal month (Crelin, 1973). At birth each of our lungs has about 25 million alveoli and this increases to about 300 million by the time we are adults (Crelin, 1973). Flattening out all our alveoli and bronchial tubes (if we were so inclined) would give a surface area of about eighty square meters, the same as a tennis court (Clements, 1962).

Activities :

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1. Lab Demonstration; Surface tension is the force that pulls together the surface molecules of a liquid, thus forming a "skin". Very carefully float a needle on the surface of a dish of water. Now place a sliver of soap in the water. It works to reduce the surface tension (as does surfactant) and the needle sinks.

The Circulatory System :

In the fetal circulation all the blood flows through the placenta which supplies the fetus with food and oxygen. Only five to ten percent of the fetal blood moves through the nonfunctioning lungs, just enough to keep them alive.

The diagram on the next page shows the fetal circulation:

THE CIRCULATORY SYSTEM: Adult and Fetal

(figure available in print form)

Blood containing oxygen and dissolved food returns from the placenta through the umbilical vein.

It enters the right atrium via the inferior vena cava. Instead of then being pumped into the right ventricle, it moves through a hole between the two atria called the *foramen ovale* and ends up in the aorta without going to the lungs.

Blood coming from the head in the superior venacava enters the right atrium also and then the right ventricle but on its way out the pulmonary artery it is shunted over a bypass called the *ductus arteriosus* into the aorta so it also avoids the lungs.

What happens at birth? As soon as the neonate draws its first breath and the cord is cut, pulmonary blood flow increases by two hundred percent (Crelin, 1973) and the pressure of the blood returning from the lungs to the left atrium closes the valve of the foramen ovale.

With the increased oxygen pressure the ductus arteriosus also closes functionally and eventually is converted into a ligament. Occasionally the ductus arteriosus and foramen ovale remain open in premature babies who are suffering from hypoxia.

Activities:

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1. On the preceding page there are two diagrams of the circulatory system, both fetal and adult. They can be xeroxed for your students and then colored in and contrasted as to sources of oxygen in the fetus and adult. There are two transparencies at the Teachers Institute which show the oxygenated (red) and deoxygenated (blue) blood.
2. Dr. Mahoney's ultrasound photos also show the development of the heart.

Fetal hemoglobin and red blood cells :

The fetus as we have seen is totally dependent on oxygen from its mother's lungs. This oxygen travels around the mother's bloodstream attached to the hemoglobin molecules of the erythrocytes, arrives at the placenta, diffuses across into the fetal bloodstream and finally reaches the fetus at a much lower oxygen pressure than in the maternal blood. This reduced oxygen pressure is about the same as that on the top of Mount Everest, certainly not enough for an adult.

The fetus, however, copes with this low pressure in several ways. First of all its heart beats extremely fast, about 150 times per minute, compared to an average adult rate of only seventy to eighty times. This ensures a swift movement of fetal red blood cells to pick up placental oxygen (it takes only thirty seconds to make a complete fetal round trip.)

The fetus has more red blood cells per cubic millimeter than an adult (seven million/mm^3 compared to an average adult value of five million/mm^3).

Fetal red blood cells also have a greater affinity for oxygen at a lower oxygen pressure than adult red blood cells.

Fetal erythrocytes are larger (8.3 microns) as compared to adult cells (7.5 microns) and thus each fetal cell can carry more oxygen.

Hemoglobin F (fetal) is found in most red blood cells before birth while hemoglobin A (adult) predominates after, but it is not clear that HbF has a greater affinity for oxygen than HbA.

The formation of red blood cells and different kinds of hemoglobin in the embryo and fetus is fascinating. The first site of red blood cell formation is the embryonic yolk sac at about three weeks (see photos in Nilsson, 1977). This organ disappears before three months but meanwhile the embryonic liver is making red blood cells (from thirty-five days and well into pregnancy). The final fetal site is the bone marrow which starts erythrocyte production at about the third to fourth month of pregnancy and continues throughout our adult lives.

At birth, the marrow of all our bones is making blood cells but in adults, only the vertebrae, ribs, sternum, part of the skull and the proximal ends of the humerus and femur are still engaged in red blood cell production (Crelin, 1973).

Three different hemoglobins are produced by the unborn child, with one switching off as the next one starts production. The different hemoglobins all contain the same heme molecules with an iron atom in the center but they all have different globins (amino acid chains) designated by Greek letters.

For the first eight weeks of prenatal life most of the hemoglobin is of the type called embryonic hemoglobin (HbE). Production of this is soon ended and fetal hemoglobin (HbF) becomes the single most important hemoglobin. At thirty-five weeks , ninety percent of the fetal cells still contain HbF but it is starting to decrease and the amount of HbA (adult hemoglobin) begins to increase. At birth the production of HbF is almost totally switched off, so that in a normal year-old child only two percent of the red blood cells contain HbF while the great majority contain only HbA. This switching on and off of hemoglobin production is under the control of certain regulatory genes. Occasionally something goes wrong and an adult never develops any HbA-his red blood cells contain only fetal hemoglobin. Luckily he can lead a completely normal life (Singer and Hilgard, 1978).

Fetal hemoglobin *does* protect individuals in certain cases. If an infant has been born with sickle cell anemia (two genes for hemoglobin S) it will not show any symptoms for the first six months of its life, as long as there is still some HbF in its blood to protect it.

Activities:

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1. At the Department of Human Genetics, Yale, there are slides available showing both maternal and fetal red blood cells. (The size difference is obvious.)
2. There is an excellent article in Scientific American, February, 1970 called "The Physiology of High Altitude" by R.J. Hock which describes the adaptations of the bodies of Andean Indians to their rarified environment. In many respects the adaptations are similar to those of the fetus inside its mother.

Immunity :

Our bodies are constantly being bombarded by viruses, bacteria and fungi, many of which live happily on our skin. It has been estimated that a normal adult male has approximately 2.41 million bacteria per cm ^{2} in his armpit (Marples, 1969). We stay healthy, however because we have a system of immunity that destroys most of the germs that penetrate our bodies.

When bacteria, for instance, enter the bloodstream they are recognized as foreign matter (antigens) by special white blood cells called lymphocytes which then divide repeatedly to form plasma cells. These plasma cells produce and release into the blood stream great quantities of protein molecules called antibodies, which are specific in their action against that antigen. The antibodies may cover the antigen by attaching to it or damage it in other ways. Other lymphocytes produce memory cells which are programmed against future invasions of that particular antigen.

The of antibodies that are of most importance to the fetus/newborn are IgG, IgM and IgA. (Ig stands for immunoglobulin.) They have different shapes and functions:

name	shape	function
IgG		Found in blood serum and can cross placenta. Protects fetus and newborn.
IgM		Found in blood serum. Destroys microorganisms. Does not cross placenta.
IgA		Found in intestines, milk, tears lining of nose. throat and lungs. Keeps germs from entering body.

(Figure available in print form)

The unborn baby lives in an almost germfree state inside the womb with the placenta as guardian against foreign attacks. At first the fetus does not make its own antibodies but is sent IgG by its mother. These different IgG antibodies are a collection of responses of the mother's body to all the microorganisms to which she has been exposed. IgG is the only group of antibodies that can cross the placenta.

Meanwhile the fetus starts to produce IgM in its spleen and bone marrow after the tenth week and the level slowly rises to birth. (IgM does not cross the placenta.) If the neonate has very high levels of IgM in its blood at birth it is suspected that it had an intrauterine infection.

At birth as the baby moves through the vagina it starts to pick up the first of the billions of microorganisms that will be with it through life. How is it protected? First of all many of its white blood cells (leukocytes) are able to engulf these germs. Also it still has a high level of IgG which was passed to it from its mother and in addition, it can make its own IgG and IgM now.

The newborn is very vulnerable to intestinal infections, though, because it has almost no IgA which would protect it. If a new mother nurses her baby she produces colostrum, a yellowish liquid, for the first few days after birth. Colostrum contains lots of IgA as does the milk which follows. A breastfed baby has less diarrhea than a bottlefed baby (Meyer and Dwyer, 1980).

The baby also passes its germs by bodily contact to the mother who makes specific antibodies against them and returns them in the milk. Thus the nursing baby and mother continue to form the same close unit that they did prenatally with the mother providing immunologic protect— ion until the baby's immature antibody system develops.

Keep warm :

We are warmblooded (homeothermic) creatures who have to expend a fair amount of energy to maintain our temperatures at about 37°C. When we are slightly cold the smooth muscles of our arterioles contract, preventing heat loss from the blood; if that doesn't help we start shivering and when all else fails we produce thyroid hormones which cause food to be burned. We also have layers of fat (more in some of us than others) which insulate us. When we are too warm our arterioles dilate releasing heat and we also sweat.

Staying warm is no problem for the fetus; its mother's body provides the necessary heat. In fact because of the high metabolic rate of the fetus and the placenta, the fetus tends to be about 0.5°C warmer than its mother so that heat is released to her. As a result pregnant women often feel warmer than usual.

Once the fetus is born its thermal free ride is over. It is forced, wet and naked, out of its warm intrauterine environment into a cold delivery room. Its body temperature may quickly drop a few degrees because it is lacking some of the adult devices for keeping warm. The newborn does not have a well-developed shivering mechanism and its layer of fat may be quite thin. It also has another handicap: its volume is about five percent of that of an adult but its surface area is fifteen percent (Niswander, 1976).

This means that it has relatively more surface area than an adult, from which heat can escape into the air.

How *does* the newborn counteract the loss of heat? Not very successfully at first. It can cry, thrash around and flex its limbs (to reduce surface area) but this is not effective. Its real weapon against cold is brown fat.

Brown fat is a tissue that actively produces heat in contrast to normal white fat which just serves as insulation. We adults do not have this type of fat but strangely enough, hibernating animals do, and it warms them fast as they wake up from a winter's sleep(Dawkins and Hull, 1965). During most of its development the human fetus is making the normal white fat used for insulation and as an energy source after birth but around the ninth month it starts producing brown fat between the shoulder blades, around the neck, down the breast bone and around the kidneys. (See diagram on this page.)

What is so special about brown fat? Unlike white fat its cells have a large number of mitochondria which metabolize the fat to produce heat, which is then carried to other parts of the body by the rich blood supply. Thus the neonate can produce heat by other means than shivering (this is called nonshivering thermo genesis). If a newborn is cold the nape of its neck where the brown fat is located will always be a few degrees higher than the rest of its body.

What a shame that we adults weren't able to retain this method of heat production. It would have been useful, but unfortunately the brown fat of the newborn soon turns into white fat.

(figure available in print form)

Newborn infant showing areas of brown fat (cross hatching)

Digestion and nutrition:.

Younger students sometimes think that the fetus eats pieces of mashed potatoes and hamburger sent to it by its mother. It *is* true that the fetus is completely dependent on its mother for food but the main source of energy is glucose, not bits of pizza. It may seem a monotonous diet for nine months but glucose, amino acids and fatty acids alone are enough to cause the tremendous increase in size of the fetus. The glucose diffuses from the maternal bloodstream into the placenta where it may be stored as glycogen (animal starch) and then into the umbilical vein of the fetus.

Insulin which is made by the pancreas of the fetus as early as three months is necessary for the fetal cells to metabolize the glucose. The amount of insulin produced is directly correlated with the concentration of glucose. Therefore a diabetic mother with a high glucose level causes her fetus to produce extra insulin which in turn causes a large uptake of glucose by fetal cells and accumulation of fat. In other words, the baby will be very large at birth, often weighing over ten pounds.

Even though all its nutritional needs are taken care of by the mother, the fetus has to start developing and exercising its own digestive system so it will be able to eat when it is born. The fetus practices by swallowing amniotic fluid as early as eleven weeks. At the same time peristalsis and absorption occur in the small intestine.

Swallowing amniotic fluid is useful for two reasons in addition to the exercise it gives. The fetus helps control the volume of fluid by swallowing it. (Urine contributes significantly and increasingly to amniotic fluid volume from early in the second trimester.) It may ingest up to 750 ml per day in late pregnancy according to Crelin (1973). If for some reason the fetus is unable to swallow, the volume of fluid could even triple. This abnormal condition is called hydramnios or polyhydramnios. The second reason for swallowing amniotic fluid is that it contains a tiny amount of protein so that the fetus actually derives a little nourishment.

When a fetus drinks the amniotic fluid it also ingests lanugo (fetal hair) and discarded cells. All of this debris accumulates in the large intestine as meconium, a sticky greenish substance that is excreted during the first few days after birth.

The baby stores reserves of glycogen in its liver and muscles preparatory to birth. After it is born it rests and lives on these reserves (and an occasional bottle of sugar water) until the mother's colostrum and then the milk come in a few days later. During this quiescent time its body is adjusting to its new environment (Brazelton, 1972).

The term baby is well adapted to sucking. It pulls the nipple far into its mouth so that ridges on the hard palate hold it in place. Its broad flat tongue then makes a channel for the milk.

The baby is able to breathe comfortably through its nose during prolonged periods of sucking, an impossibility for an adult. There is an anatomical explanation. The newborn's larynx is located so much higher in its throat than that of an adult that the opening (covered by the epiglottis) is above the stream of milk and the baby can breathe and eat at the same time without choking. At about three years of age, the larynx moves down into the throat along with the back of the tongue which is fastened to it (Crelin, 1973).

Activities :

1. Dr. Cara Smith of the Department of Human Genetics at Yale, has generously offered to make samples of amniotic fluid available so that students can study its components. Also slides of amniotic fluid cells which have been cultured for their chromosomes.
2. Lab exercise to show that diffusion across a membrane (placenta) is often inversely proportional to the size of the molecules. Make a "sausage" of dialysis tubing and pour in a solution of glucose and starch. Suspend by a string in a small beaker of water. After a few minutes test the water to show that glucose is present (Benedict's solution) but starch is not (iodine).

The nervous system and reflexes :

We sometimes wonder whether the fetus is aware of its environment and consciously responds to it, or whether it is basically a creature of automatic reflexes. Perhaps the best way to decide is to study the development of its nervous system. The drawing on the next page of the developing human brain shows clearly the tremendous growth and fissuring of the cerebrum [2] .

The human embryo' s brain starts to develop extremely early, at about three to four weeks, immediately after the heart begins to beat. It then grows so fast that by the sixth fetal month all the 100 billion or so neurons that are present in our adult brains have formed already. It has been calculated that to make this many neurons the unborn baby would have to produce 250,000 neurons every minute of fetal life (Cowan, 1979).

(Figure available in print form)

Early pregnancy is obviously a crucial period in the development of our brains since only then are our bodies making neurons. This is the worst possible time for the mother to contract rubella, herpes or other viral diseases which are transmitted across the placenta. All of these infections as well as excessive radiation will kill neurons, leaving the individual with a reduced number and possible retardation.

The six month fetus has as many neurons as an adult but the development of the brain is by no means complete yet. There are relatively few pathways in the fetal brain because the neurons have not branched to form many synapses; each neuron when it is fully mature may have up to 10,000 connections. Also, special brain cells called neuroglia cells which appear at the same time as the first neurons, keep multiplying long after the neurons stop and eventually form about half of the brain weight. These cells are important because they help feed the neurons and also coat them with a fatty insulating layer called myelin. Myelinated neurons can carry nerve impulses much faster and with much less expenditure of energy than unmyelinated cells

(Morell and Norton, 1980). Myelination is often used as the main criterion in deciding whether a certain part of the nervous system is fully functional or not.

Maturation in the central nervous system proceeds from the tail to the head end, in contrast to most other systems. First the spinal cord begins to exercise control to allow some basic reflex actions to occur. The very earliest reflex that has been observed is the avoidance movement of the head of a seven week embryo when its upper lip was stroked. (This is also when the first muscle cells begin to contract, Crelin, 1973).

The medulla which controls swallowing, coughing, breathing and other vital functions, becomes myelinated at about five months. A fetus as young as eleven weeks has been observed to swallow if its lips were touched but the movements were probably not well coordinated. A thirteen week fetus has irregular chest contractions but real breathing movements do not start until. after five months. All these reflexes are controlled by the medulla.

There would seem to be no need for the fetus to suck its thumb in utero, flex its limbs, hiccup, wrinkle its face and swallow but it is of course practicing for its future life outside the womb. Muscles and organs that do not get used tend to atrophy.

The cerebral hemispheres are still not well myelinated at birth so that the newborn is in many ways a reflex creature like the fetus. Many of these reflexes which are controlled by the spinal cord or midbrain may now have great survival value. For instance, the rooting reflex which causes a baby to turn its head towards a touch on the cheek and at the same time to open its mouth allows the newborn to find its mother's breast and nipple. The importance of the sucking reflex is obvious: when anything is put in the newborn's mouth, be it the pediatrician's finger or the mother's nipple, it starts sucking vigorously. Swallowing goes along with sucking but often, premature babies are unable to coordinate these two activities.

There is a very common startle reflex among new babies called the Moro response which has no obvious survival value but which may be a holdover from our ape ancestry according to Brazelton (1969). The baby suddenly throws out its arms, pulls up its legs, cries and then brings its arms in again. It does this continually if upset. Brazelton speculates that the baby may feel that it is falling so tries desperately to grab on to something (like its mother of a tree branch, to carry on with the ape analogy).

Newborns can also "walk" if they are held with their feet on a flat surface and can "crawl" if placed on their stomachs with pressure against their feet. All these reflexes persist in the first few months after birth and then usually disappear as learned responses become more important for the baby. In fact, if reflexes, like the Moro response , persist it may be a sign that something is wrong neurologically.

The neonate quickly starts to respond to its new environment in a more conscious fashion in addition to its automatic reactions. Right after birth there is usually a period of wakefulness for the neonate, lasting up to an hour. The baby is very alert at this time despite its recent trauma and may interact with its new mother in an intense fashion. They gaze into each other's eyes and the mother usually touches her baby all over and talks to it. This process is called bonding.

There are several other things that the newborn is capable of that are probably controlled by its cerebrum. For instance, in the delivery room it can turn its head to follow slowly moving brightly colored objects; although it soon prefers the human face, especially its mother's, as an object of contemplation. Interestingly enough, the newborn focuses best at about twelve inches, which is the distance a nursing mother holds it from her face. Very soon the new baby produces an occasional smile, completing its conquest of its mother, The more these responses, controlled by the cerebral cortex, are repeated the more associations are developed in the brain, In former times when unwanted babies were often institutionalized, the lack of stimulation in the wards caused these children to become apathetic and sometimes retarded;their brains simply had no reason to develop.

We humans are unique because we have the largest brains relative to body size of any species, but despite this, when we are born we are almost totally helpless, unlike the newborn of deer or horses which can run after their mothers in a few hours.

The newborn human brain weighs about 350 grams, ten percent of its body weight, so that the head is a very large part of the body. In fact, the circumference of the skull is one centimeter larger than the mother's fully open cervix, but because there are several separate skull bones that can overlap slightly at their edges, and soft spots called fontanelles, molding of the skull takes place during birth without any danger to the brain.

The newborn's brain is large but the growth that occurs in the first year is truly phenomenal-a threefold increase from 360 grams to 1000 grams. If this increase had occurred inside the womb before birth, the human race would have been extinct long ago:

Activities:

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1. Dr. Ronald Angoff, a pediatrician at St. Raphael's Hospital, has made a series of slides showing the reflexes of newborns for this unit. These slides, courtesy of St. Raphael's, are available by calling me at McGabe Center, 787-8758. (I am very grateful for his help and participation.)
2. Dr. Angoff has also made videotapes of newborns and toddlers that he will be glad to show to school classes. He may be contacted at his office, 789-3737. (These videotapes were enthusiastically received by students at McCabe but would be of general interest to all classes.)
3. Dr. E. Crelin of the Yale Medical School has models of the developing human brain which he has graciously consented to lend. Contact me at McGabe, 787-8758, for more information.

MATERIALS FOR CLASSROOM USE:

At the end of each section I have listed materials and resources which are available from Dr. M.J. Mahoney and Dr. C. Smith of the Department of Human Genetics, Yale, as well as Dr. E. Crelin of the Yale Medical School. I greatly appreciate their kindness in sharing so many resources, and suggest that interested teachers call me at McCabe (787-8758) so that I can coordinate the borrowing.

At the Teachers Institute a package containing the following transparencies may be borrowed. (53 Wall St., 436-3316)

a) Placenta at term

b) Fetal and adult circulation

c) Developing human brain

d) Cross section of the placenta

e) What affects fetal growth? (seven transparencies)

LESSON PLAN I: Demystifying the Placenta

Objectives The placenta which plays such a major role in pregnancy has a rather complicated structure and numerous functions. This lesson plan is a step-by-step approach to understanding this multifaceted organ.

Strategies:

1. Show your students photos of the placenta from “A Child is Born” by Nilsson (pp 81, 128-9) and Beaconsfield, 1980, (pp 94, 98).
2. Draw a circle on the board twenty centimeters in diameter with the cord attached to the center to represent a life size placenta. Ask your class to figure how much it weighs if its ratio to an eight pound baby is 1:6.
3. Make copies of the diagram on the next page called “Gross section of the Placenta” for each student. Discuss how the maternal side is different from the fetal side. Then have them color in the blood vessels (red for oxygenated blood and blue for deoxygenated). There is a transparency at the Teachers Institute which you can use as a guide.
4. Emphasize that the fetal villi which contain thin-walled capillaries are bathed in maternal blood, and that this is where all exchanges of materials take place.
5. There are three empty boxes on the diagram of the placenta marked: FETUS SENDS TO MOTHER, MOTHER SENDS TO FETUS, PLACENTA MAKES THESE HORMONES. Use the information below and see a) if students can figure out which box each substance belongs in and b) what effect it could have on either fetus or mother.

For instance, *glucose* , is sent to fetus from mother and it supplies energy. (Don’t be too quick to give answers).

MOTHER SENDS TO FETUS

oxygen

water

glucose

fatty acids

amino acids

vitamins and iron

carbon monoxide

alcohol

heroin

nicotine

viruses (such as rubella & herpes

IgG antibodies which protect against some diseases.

PLACENTA MAKES THESE HORMONES

HCG (human chorionic gonadotropin)

HCS (human chorionic somatomammotropin)

progesterone

estrogen

FETUS SENDS TO MOTHER

carbon dioxide

urea and uric acid

bilirubin

heat

(figure available in print form)
CROSS section of the placenta

LESSON PLAN II: What Affects Fetal Growth?

Objectives Many maternal factors may influence fetal growth including nationality, smoking, high blood pressure, diabetes and socio-economic level. Twins also have a different growth curve than single babies.

This lesson plan uses graphs to show students how the growth curves may vary due to these different conditions. It also indicates that growth always levels off towards term (40 weeks from last menstrual period) probably because the placenta is no longer adequate to supply the fetus.

Strategies:

1. There are a set of transparencies at the Teachers Institute, one for each growth curve, which may be superimposed on each other using an overhead projector. They are based on the following graph from Gruenwald (1966).
2. Give each student his/her own graph (copy next page). First have them convert the weights on the ordinate from grams to pounds by multiplying by. 0022.
3. *Transparency I: Average fetal growth curve* . Before you show it to class ask them to guess the average weight of a baby at term (40 weeks). Have them draw in the curve on their graphs from the transparency.
4. Repeat with the other overlays. Ask students to
    a) guess the weight at term for each variable;
    b) figure out why it varies from the average; and
    c) draw the curve on their graphs.
5. Discuss why the curves level off after 40 weeks. (The placenta seems to age and is no longer capable of supplying the fetus with all its needs.)

Fetal Growth Curve (From P. Gruenwald. *Am J Obstet Gynec* 94:1112, 1966).

(Figure available in print form)

WHAT AFFECTS FETAL GROWTH?

(figure available in print form)

LESSON PLAN III: Eliminating Fear and Loathing of Scientific Words

Objectives Scientific words can be overwhelming for many high school students but they can also be fun if approached as a guessing game. The thing to be avoided is memorization of lists. Students don't realize that those ponderous words are made up of short Latin and/or Greek roots that scientists have strung together and that if they know what the roots mean they are home safe, because they will begin to see them everywhere. (Puerto Rican students will be delighted because they will know so many of the roots.)

Strategies I've picked out many of the scientific words in this unit plus some others that will help reinforce their meanings. The roots in the words have been underlined so that by using the List of Latin/Greek Roots, students can write down the literal word meanings. Xerox both the List and the words, so that your students can work independently at first. (You may want to delete or add.)

Example: LEUKOCYTE LEUK = white CYTE = cell

Hence, white blood cell.

List of Scientific Words

pre *natal*	*cyto logy*	*vena cava*
neo nate	*leuk* o *cyte*	intra *venous*
peri nat ology	*erythro cyte*	leuk emia
peri meter	*hemo cyto meter*	*an emia*
thermo meter	*hemato logy*	*tox emia*
hypo thermic	circum *cision*	post *partum*
hyp oxic	in *cision*	anti *biotic*
carbon *di oxide*	in *halation*	gyneco logy
carbon *mono ox* ide	*ex halation*	ped iatrician
bio logy	*ex cava* tion	

List of Latin/Greek Roots

a, an = without	gyn = woman	natal = birth
anti = against	hal = breathe	neo = new
bi,di = two	hem = blood	ox = oxygen
bio = life	hyper = too much	partum = birth
cava = hollow	hypo = too little	ped = child
circum = around	ician = specialist in	peri = around
cis = cut	in,intra = in or inside	post = after
cyt = cell	leuk = white	pre = before

emia = blood	logy = study of	therm = heat
erythro = fed	meter = measure	tox = poison
ex = out	mono = one	ven = vein

Follow-up Activity:

1. When students have finished word meanings have a scientific word "bee" with the class split in two. Vary the questions by asking if a student can think of other words that contain the roots. For instance, for MONO, answers could monocle, monogamy, monotonous, monogram etc.

Notes

1. H.E. Evans and L. Glass, *Perinatal Medicine* . Harper and Row, New York, 1976, p. 1.
2. From "The Development of the Brain" by W. Maxwell Cowan. Copyright © September, 1979 by Scientific American, Inc. All rights reserved. (There is also a transparency at the Teachers Institute.)

Teacher Bibliography:

Many of the books that I read for this unit are in the Yale Medical School Library and therefore somewhat inaccessible. If you are interested in the topic I would suggest starting with the following articles, all of which are from *Scientific American* .

Avery, M.E., Wang, N-S., and Taesch, H.W., The Lung of the Newborn Infant. 228:4, 1973.

Beaconsfield, P., Birdwood, G., and Beaconsfield, R., The Placenta. 243:2 1980.

Clements, J.A., Surface Tension in the Lungs. 207:6, 1962.

Gowan, W.M., The Development of the Brain. 241:3, 1979.

(This whole issue is devoted to brain function and structure.)

Dawkins, M.J.R., and Hull, D., The Production of Heat by Fat. 213:2, 1965.

Gray, G.W., "The Great Ravelled Knot", 179:4, 1948

(The rather mysterious title refers to the brain.)

Kappas, A., and Alvares, A.P., How the Liver Metabolizes Foreign Substances. 232:6, 1975.

Marples, M.J., Life on the Human Skin. 220:1, 1969.

Morell, P., and Norton, W.T., Myelin. 242:5, 1980.

Most of the following books are in the Yale Medical School Library, except for the Crelin volume which is at the Teachers Institute.

Austin, C.R., and Short R.V., editors, *Reproduction in Mammals* , Book 2 and Book 3.,Cambridge U. Press, 1972.

This is the best reference on pregnancy hormones that I read.

Burnham, S., “The Heroin Babies:Going Cold Turkey at Birth”. *The New York Times Magazine* , January 9, 1972.

Vivid descriptions of the agonies of addicted newborns.

Crelin, E.S., *Functional Anatomy of the Newborn* . Yale U. Press, New Haven, 1973.

A definitive work on the newborn based on Crelin’s own studies. Fascinating because its speculations are based on such painstaking observations.

Evans, H.E., and Glass, L., *Perinatal Medicine* . Harper and Row, New York, 1976.

This is one of the books I used the most. Good survey of a new field.

Goodwin, J.W., Godden, J.O. and Chance, G.W., *Perinatal Medicine.* The Williams and Wilkins Co., Baltimore, 1976.

Chapters by different authors. Technical and thorough.

Meyer, J. and Dwyer, J., Breast-fed babies have best immunity.

New Haven Register, January 6, 1980 p. 40.

Short article on advantages of breast feeding.

Moore, Keith L., *Before We Are Born* . W.B. Saunders Co. Philadelphia, 1977. Many excellent drawings and also photos, some of which you may wish you had never seen.

Niswander, K.R., *Obstetrics.* Little Brown and Co., Boston, 1976 Not difficult. Much useful information about the baby.

Singer, S. and Hilgard, H.R., *The Biology of People* . W.H. Freeman & Co., San Francisco, 1978.

The best general text on human biology. Much of the information comes from Scientific American.

Student Bibliography:

Brazelton, T. Berry, *Infants and Mothers.* Delacorte Press, New York, 1972. Follows the development of three babies from birth to their first birthday, in a fictional form with medical asides.

Demarest, R.J. and Sciarra, J.J., *Conception, Birth and Contraception* . McGraw-Hill Book Co., New York, 1976.

Excellent drawings of fetal development.

Nilsson, Lennart, *A Child Is Born* ., Delacorte Press, New York, 1977. The most popular book at my school because of the multitude of colored photographs showing every aspect of prenatal development and birth. (Copies at the Teachers Institute)

———, *How Was I Born* ? Delacorte Press, New York, 1981. A book for younger students or lower level readers. Includes many of the same photos as in Nilsson's other book.

Rugh, R. and Shettles, L.B., *From Conception to Birth* . Harper and Row, New York, 1971.

Appropriate for more advanced students. Some photos.