NORMAL RHESUS MONKEY assumes an alert, crouching stance soon after birth. Curious and playful, it can feed itself easily by sucking on a bottle. At about three months the infant monkey will be more advanced than a human child three or four years old.

ABNORMAL RHESUS MONKEY was experimentally subjected to asphyxia at birth. Like a child suffering from cerebral palsy, this monkey is unable to use its arms and legs normally. It sprawls, and it will not move unless prodded. It is also unable to feed itself.

Brain Damage by Asphyxia at Birth

In both monkey and human infants handicaps that arise from such asphyxia seem to disappear with time. Experiments with monkeys, however, demonstrate that asphyxia permanently damages the brain

by William F. Windle

Birth is a normal physiological event. Most animals that bear live young pay no more heed to it than they do to their everyday activities. The human animal is exceptional. He has come to look on the time of birth as one of the most critical in the life of both mother and child, and rightly so. There are many things that can go wrong with the delivery of the human infant. Not the least of the hazards is asphyxia that can lead to brain damage and possibly cerebral palsy and mental retardation. It is this hazard that I shall discuss here.

Asphyxia is a condition resulting from a disturbance of the respiratory mechanism. It has been defined as a state of suspended animation due to a lack of oxygen in the blood. In the fetus at birth it involves more than a lack of oxygen (hypoxemia). The blood of an asphyxiated newborn infant may not only contain virtually no oxygen but also contain excessive amounts of carbon dioxide and lactic acid, which lower its *p*H (that is, make it acid). The infant's heartbeat will have slowed, its blood pressure may be alarmingly reduced and it cannot begin to breathe. This combination of events is termed asphyxia neonatorum. When such asphyxia occurs, immediate resuscitation measures are of course imperative. Several stages of birth asphyxia are recognized. The hypoxemia is not always prolonged to the point where spontaneous efforts to breathe stop (terminal apnea). When asphyxiation stops short of apnea, the infant will not need resuscitation and its body functions may be only temporarily depressed.

Asphyxia neonatorum is an unnatural event that in human infants may come about because of unavoidable conditions. Among them is the fact that the human infant has a large head. Evolution has given man a highly developed brain and a skull that attains such a size at the end of gestation that its delivery is an unusual biological problem. Today many women have come to fear childbirth and to demand relief from their physician. Sometimes the well-being of the fetus is unwittingly placed in jeopardy in ensuring the mother's comfort and peace of mind. Not all factors that complicate the delivery of the human infant are clearly perceived; some, however, are recognizable and can be avoided.

The role of asphyxia neonatorum in brain damage has been debated for more than a century. As early as 1861 an English physician, W. J. Little, suggested a relationship between asphyxia during birth and neurological and mental disorders of infancy. His view was accepted by few and had little impact on medical practice, although from time to time it was advocated by others. This long debate illustrates what little influence retrospective clinical observations have had on medical opinion. In 1957 C. J. Bailey, speaking at a Puerto Rico conference titled "Neurological and Psychological Deficits of Asphyxia Neonatorum," pointed out that retrospective clinical studies can never logically answer the question of whether asphyxia at birth causes brain damage resulting in symptoms of cerebral palsy and mental retardation or whether other factors causing cerebral palsy and mental retardation also induce asphyxia. Any child with cerebral palsy or mental retardation who also presents a history of asphyxia at birth can be used as an example to support either proposition. The answer can be found only by experiment.

Over the past 15 years much experimental work has been done on asphyxia neonatorum. Obviously such investigations cannot be pursued with the human fetus; controlled experiments with animals have been designed. These experiments, in conjunction with clinical observations, have made us better able to evaluate the role of asphyxia neonatorum in brain damage and propose measures of prevention.

Earlier experiments had been conducted on asphyxia at birth in guinea pigs. Brain damage and impairment of learning ability were found, but the asphyxia required was severe and the relevance of experiments with rodents to findings in human infants was questioned. Therefore when adequate facilities and support became available workers in the field turned their attention to nonhuman primates. The experiments I shall review here were conducted in two National Institutes of Health laboratories (one in Bethesda, Md., and the other in San Juan, Puerto Rico) and more recently at the New York University Medical Center.

We chose the rhesus monkey (*Macaca mulatta*) for studying fetal physiology and its experimental alteration. We used more than 500 fetal and newborn monkeys, about a fifth of which were asphyxiated during birth. Before I turn to the experiments it will be helpful to compare the monkey's birth with the birth of the human infant. There are marked differences that bear on the relevance of comparisons between the two, but there are also many similarities.

Spontaneous neurological deficits are practically unknown among rhesus monkeys born in their natural habitat or in colonies housed in laboratories. In this respect the monkeys differ from human beings. There are a good many defective human offspring and, more important, the techniques of modern medicine can keep them alive. If defective monkeys are conceived, they die at birth and

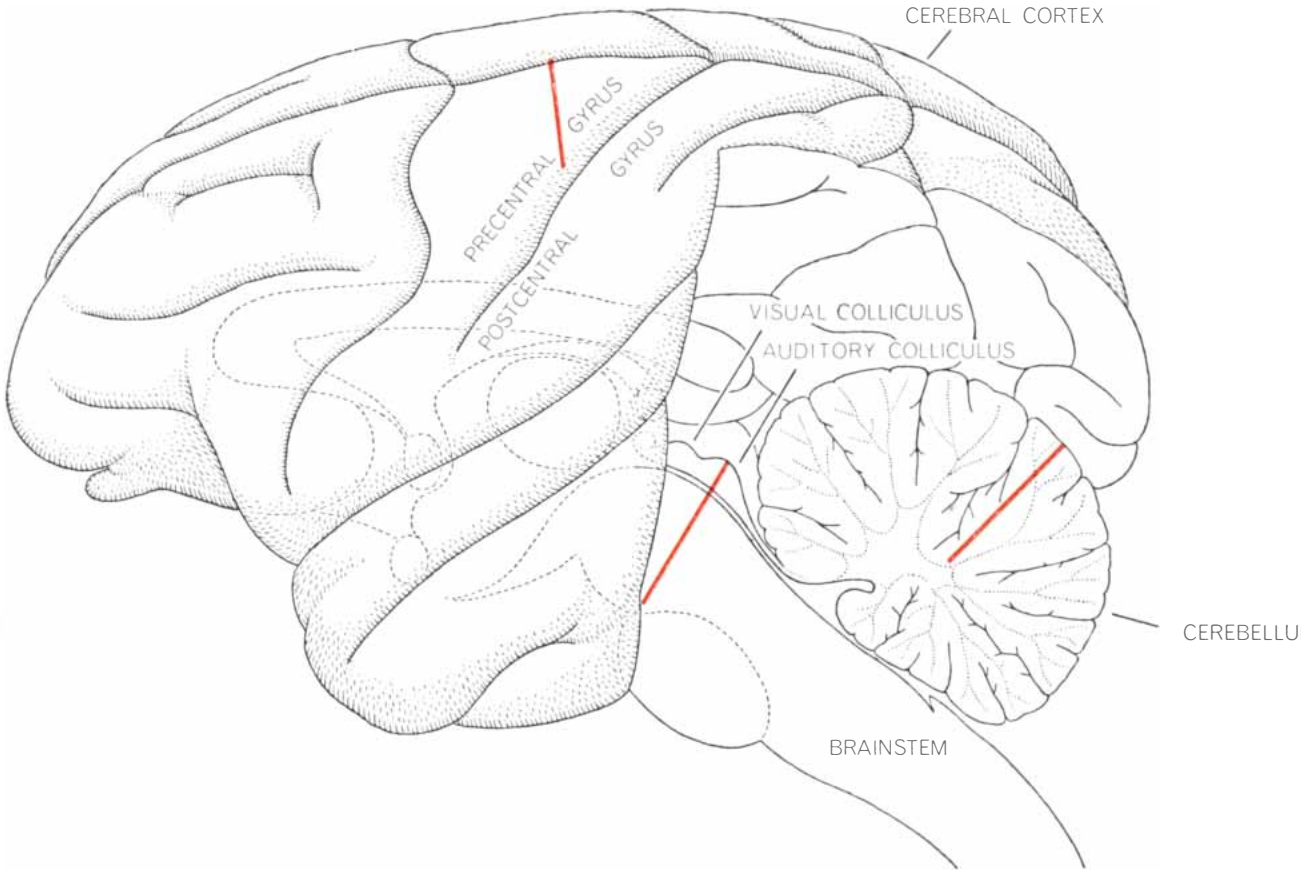
disappear from the monkey population.

Most monkey births occur at night, as is the case with human beings. Labor is short: an hour or less. The female squats and drops the infant on the ground. During delivery most of the blood in the placenta passes to the infant and, as the uterus continues to contract after birth, the placenta is expelled. Thereupon the female severs the umbilical cord with her teeth and, like most other mammals, eats much of the placenta. Human infants are born in much the same way in many parts of the world. The woman delivers, often unassisted, in the squatting position, and the infant, being below her, recovers most of the blood from the vessels of the placenta and the umbilical cord. I would not recommend that women revert to primitive ways, certainly not to chewing the umbilical cord to sever it (a practice that is still encountered in some places). Nevertheless, in any delivery it is important to keep the umbilical cord intact until the placenta has been delivered. To clamp the cord immediately is equivalent to subjecting the infant to a massive hemorrhage, because almost a fourth of the fetal blood is in the placental circuit at birth. Depriving the infant of that much blood can be a factor in exacerbating an incipient hypoxemia and can thus contribute to the danger of asphyxial brain damage.

In advanced countries, of course, the supine position of delivery is used to enable the attending physician or midwife to observe the birth conveniently and to assist if necessary. The squatting position, in addition to allowing the infant to receive the placental blood from above, has other advantages over the supine position. It avoids compression of the blood vessels supplying the placenta, which occurs in the supine patient when the gravid uterus tilts back against the pelvis. Delivery while the woman is lying on her side, however, can also avoid such compression and prevent the infant's oxygen supply from being sharply reduced. Doubtless this position would be more acceptable to American women than the squatting one.

Monkeys offer a number of benefits in experiments on asphyxia at birth. Many of the variables that cannot be avoided in human births can be controlled. Anesthetic drugs that might affect the infant's ability to begin breathing need not be administered. The production of asphyxia can be timed with some accuracy and terminated at precisely the desired moment. Most important, after observations of the behavior of a monkey that has been asphyxiated and resuscitated have been completed, the brain of the monkey can be prepared for histological examination, thus providing the kind of neuropathological material that can rarely be obtained from human subjects.

We began our experiments by inducing asphyxia in infant monkeys near the end of gestation (which lasts about six months). The fetus and its surrounding membranes were removed by Cesarean section after the mother had been given a local anesthetic. Stimulated by the asphyxia imposed by its removal from the mother, the fetus attempted to breathe while it was still enveloped in the surrounding membranes. These respiratory movements continued for eight or nine minutes. When they had stopped, the membranes were opened, a tube was inserted into the monkey's trachea and at a predetermined time artificial respiration with oxygen was started. This was continued until the infant monkey began



INJURIES of the monkey brain are produced by asphyxiation for varying periods. Lines (*color*) indicate regions that are often severely damaged by asphyxiation during birth. Asphyxia lasting more than 12 minutes creates lesions in the auditory colliculus and in deeper brain structures but does not affect the visual colliculus. It also causes degeneration of cells in the cerebellum and sometimes in the precentral gyrus of the cerebral cortex, a part of the brain concerned with such functions as memory and learning.

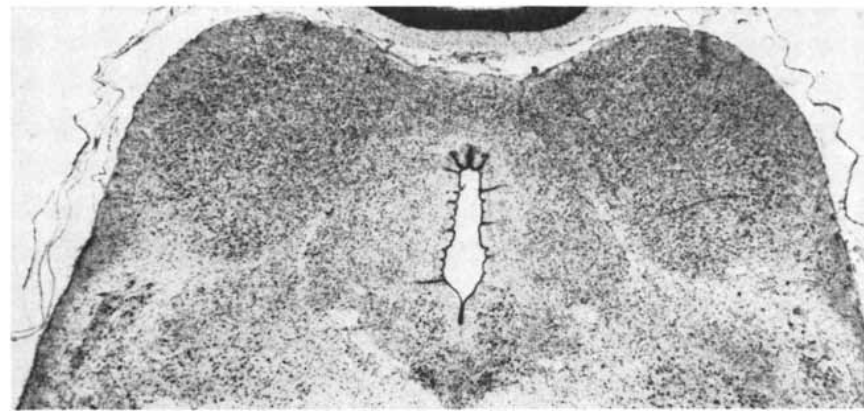
to breathe. In some experiments asphyxiation was halted before the monkey's efforts to breathe had stopped, so that no resuscitation was required. Other monkeys were delivered by Cesarean section but were not asphyxiated; these animals and some that were born spontaneously served as controls.

The period of asphyxiation ranged from four minutes to more than 21 minutes. Some of the more severely asphyxiated monkeys died soon after birth. Others were killed for neuropathological studies after as little as a few days and as much as several years. A few are still living more than 10 years after asphyxiation.

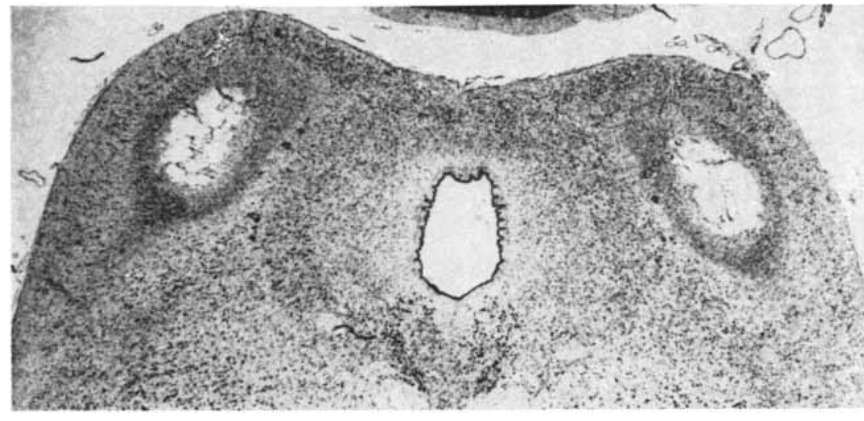
Both the experimental monkeys and the controls were raised by technicians, when necessary in an oxygen-enriched atmosphere. Periodically the animals were examined and given tests to evaluate their neurological status. The experimental procedures and the monkeys' behavior and reactions were recorded with motion pictures, which proved invaluable for later review. For the neuropathological studies each brain was sliced into as many as 5,000 sections for microscopic examination. Sections were also made at representative levels of the spinal cord.

One of our first aims was to find out how short a period of asphyxia will leave a mark and how long a period is compatible with survival. In two monkeys that had been asphyxiated for only six minutes at birth and had not needed resuscitation we detected what we termed "minimal" structural brain damage, but there was no appreciable deficit in function. At the other extreme was a monkey that had been asphyxiated for more than 21 minutes at birth and had been in coma until it was killed after three days. Nearly all parts of its brain showed severe damage. Most of our observations were made on the brains of animals that had been asphyxiated for eight minutes or more. (More than eight minutes must elapse during asphyxiation before resuscitation becomes necessary.) We found no lesions in control monkeys.

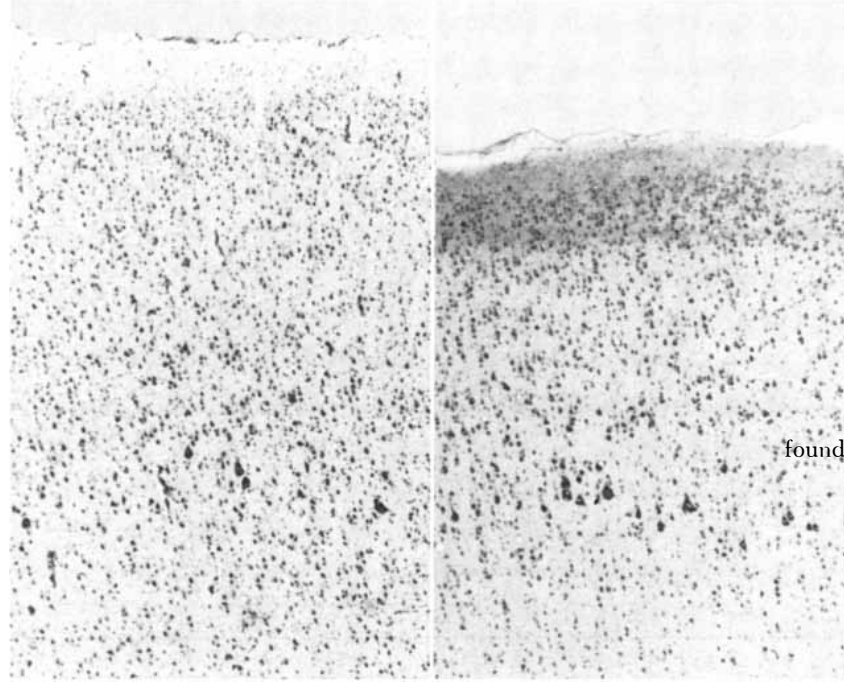
In monkeys that had been asphyxiated for eight to 12 minutes there was loss of nerve cells in the thalamus and the inferior colliculus of the midbrain (both are centers that receive nerve impulses concerned with general body sensations and hearing and relay them to the appropriate higher centers) and in some other groups of cells in the brain stem. Symmetrical lesions were produced on both sides of the brain. They were sharp-



NORMAL COLLICULUS consists of densely packed nerve cells that relay nerve impulses related to hearing originating in the structures of the ear to the higher brain centers.



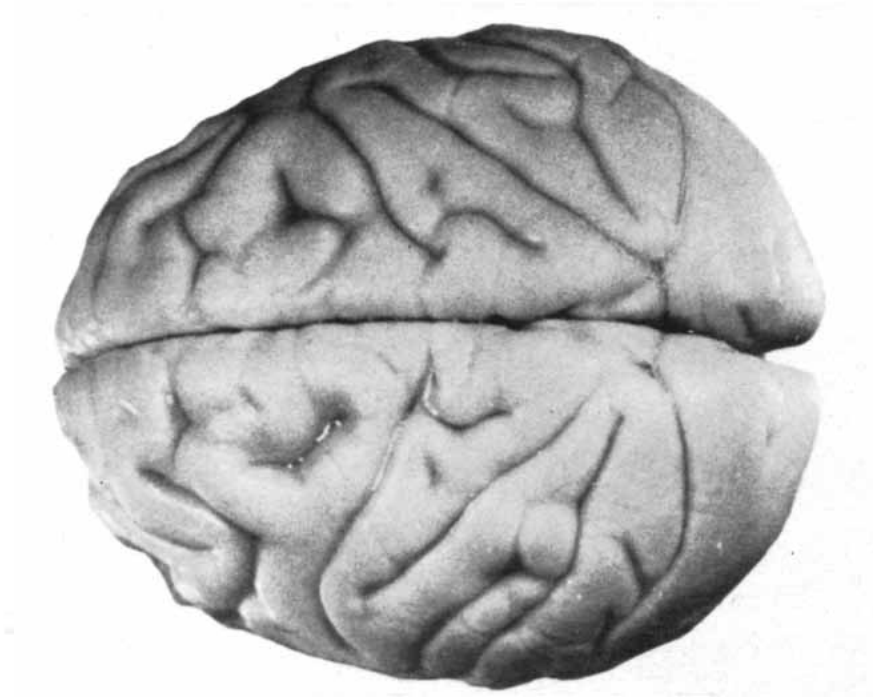
DAMAGED COLLICULUS from a monkey that was asphyxiated during birth nearly five years previously is pitted by cavities (*left and right*) left by cells that disintegrated.



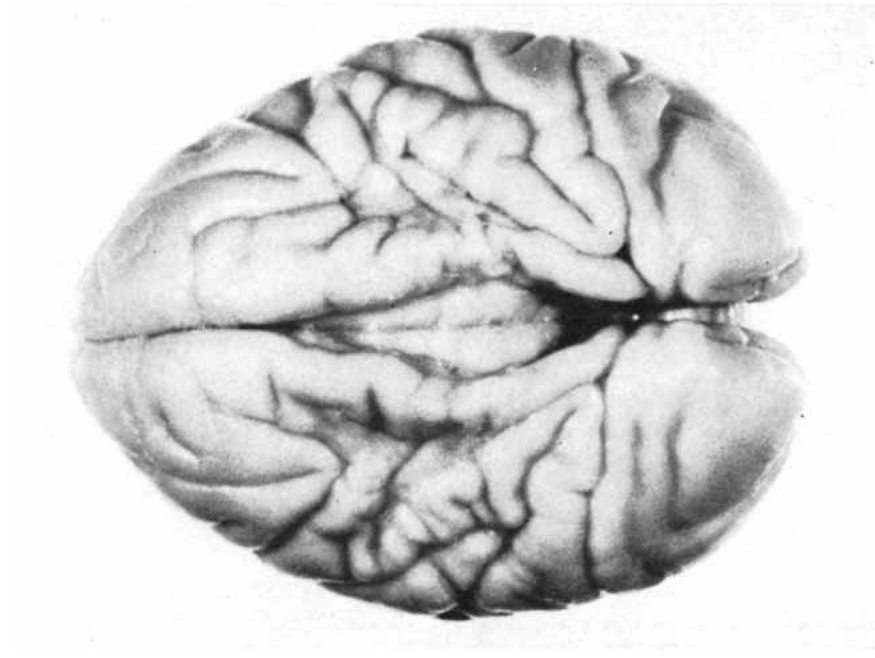
PRECENTRAL GYRUS normally consists of a thick structure of cells (*left*) organized into layers. Asphyxia at birth causes the precentral gyrus to atrophy (*right*), because cells in this structure are linked to those in the thalamus by fibers. When asphyxia destroys the cells of the thalamus, both the linking fibers and cells of gyrus degenerate and disappear.

ly circumscribed by unaffected tissue and showed no hemorrhages. Most other parts of the brain, including the motor components of the spinal cord, the cerebellum and the cerebral cortex, were also unaffected.

Monkeys asphyxiated at birth whose brains were affected in this pattern displayed abnormal neurological signs after resuscitation. They had trouble righting themselves and for a time could not move about easily. Their limb movements were uncoordinated. All of them had trouble feeding because they could not suck. These abnormalities eventually disappeared, often within a few days and at most within a few weeks. The electroencephalogram of the monkeys, when it was affected at all by such asphyxia, quickly became normal.



NORMAL BRAIN of a rhesus monkey that was not asphyxiated has a fully developed cerebral cortex. The convolutions of the cortex have a characteristically rounded form.



ABNORMAL BRAIN of a three-month-old monkey that had been asphyxiated and revived, but suffered respiratory distress, is shriveled because lack of oxygen killed tissue.

These monkeys may be comparable to human infants who encounter some degree of asphyxia at birth, have low Apgar scores (an index of the newborn infant's general condition) but recover without apparent neurological deficit. It is generally believed that such infants are normal. If one could inspect their brains as we examined the brains of our monkeys, one would probably find the same kind of lesions. It is no longer acceptable to assume that the human fetus or newborn infant is so resistant to oxygen deficiency that it will escape harm from a short exposure to asphyxia neonatorum. If the infant's brain can be compared to the monkey's, asphyxia of such duration that resuscitation was required will certainly have damaged it. The damage, although it is minimal, will be permanent even when it is clinically noticeable for only a short time or when it produces no symptoms at all. What effect such minimal brain damage will have as the child matures is not known.

Asphyxia lasting more than 12 minutes during the monkey's birth damaged brain structures more extensively and caused more pronounced functional deficits. The basic lesions of the thalamus, the inferior colliculus and the brain stem were more severe. They consisted of regions where nerve cells had degenerated and in time had been replaced by scars surrounded by normal tissue. Furthermore, there were new centers of destruction in the basal ganglia, the cerebellum and the spinal cord. The cerebral cortex and the primary motor nuclei remained less damaged than other regions. (This was true even in the brain of the monkey that had sustained more than 21 minutes of asphyxia.) The white matter in the brain and the spinal cord was not affected directly, although tracts of nerve fibers associated with cells that had been destroyed by asphyxia had themselves degenerated.

All the monkeys that had been asphyxiated during birth for more than 12 minutes and had to be resuscitated exhibited functional deficits that persisted for some time. Many required intensive nursing care. The most seriously injured animals presented symptoms resembling those encountered in human beings with cerebral palsy.

The amount of brain damage and the extent of functional loss were sometimes increased by complicating factors associated with asphyxia neonatorum or arising afterward. Some of these factors are premature birth, postnatal respiratory distress accompanied by so-called hyaline membrane disease, cerebral

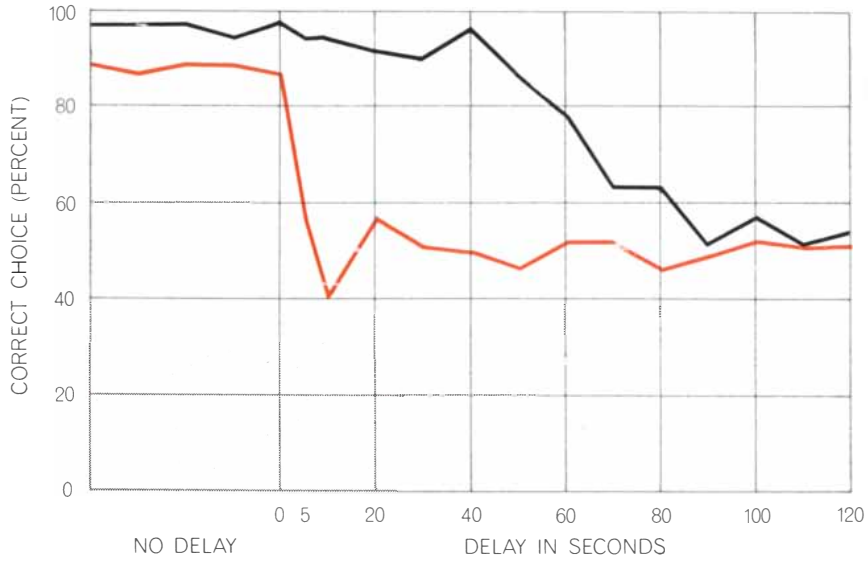
hemorrhages, swelling of the brain and the neuropathological condition known as kernicterus.

Inadequacy of lung function is often encountered in prematurely born infants. The establishment and maintenance of breathing depends on the immediate expansion and activation of the alveoli, or air sacs. The lungs attain a state of development that can support breathing well in advance of a normal full-term birth. There is a point in time, however, before which full efficiency of the pulmonary mechanism has not been attained, and if birth occurs prematurely, the lungs cannot adequately oxygenate the blood. The infant turns blue and enters a state of respiratory distress.

Postnatal respiratory distress in the monkey resembles such distress in human infants. It is manifested by rapid gasping and by inward movement of the edges of the rib cage, often accompanied by audible grunts. The monkey is pale and, even when it is kept in an atmosphere enriched with oxygen, its respiration occasionally fails and it turns blue. Respiratory distress arose spontaneously in only four out of 90 of our nonasphyxiated infant monkeys, and three of these were so premature that their lungs were incapable of normal function. In contrast, the incidence of respiratory distress was high (50 percent) among 68 monkeys that had suffered asphyxia neonatorum or other kinds of experimentally induced crisis.

Some of the monkeys exhibiting respiratory distress and requiring intensive nursing care in incubators supplied with oxygen showed evidence of added neurological deficits. When their brains were examined later, certain regions of the cerebral cortex were found to have undergone marked degeneration. Thus it appears that postnatal respiratory distress can increase the brain damage of asphyxia neonatorum, and although it is not the primary cause of damage in such disorders as cerebral palsy and mental retardation, it is surely an important contributing factor.

When the lungs of some of the monkeys that had failed to survive were examined, membranes were found in the alveoli similar to those seen in some human infants who are said to have died of hyaline membrane disease. Such membranes interfere with the normal exchange of carbon dioxide and oxygen in the alveoli. They were not encountered in the lungs of monkeys that had not been asphyxiated. The formation of hyaline membranes appears to be a manifestation of abnormal pulmonary function. This condition is therefore not really a disease but an effect of the asphyxia. It can be prevented but not cured.



TEST PERFORMANCE shows that monkeys with atrophied brain tissue have a diminished ability to remember. In this test experimental and control monkeys watched through a plastic window as a food pellet was placed in one of two covered containers. The window was then opened so that the monkey could take the food. If the opening of the window was delayed for five seconds or more, the monkeys that had suffered asphyxia 10 years earlier (*colored curve*) reached for the food receptacle only about 50 percent of the time, a record that was no better than what would have been expected on the basis of random choice.

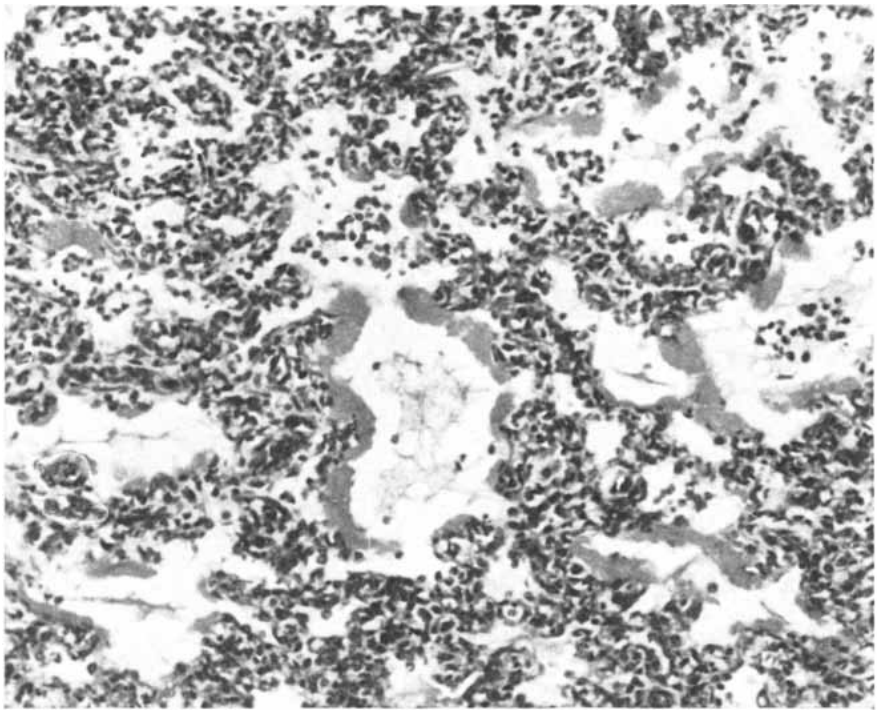
As for the complicating factor of cerebral hemorrhage, it is widely believed asphyxia neonatorum produces little hemorrhages in the brain, because they are sometimes found after death in human infants who had suffered asphyxia at birth. The belief that hemorrhages in the brain are the result of asphyxiation is so firmly held in some places (notably France) that if an infant is found dead in its crib with its face up, and if postmortem examination by the medical examiner discloses hemorrhages, the death is likely to be considered homicide by suffocation. Experimental findings in monkeys place brain hemorrhages of the newborn in a different light.

The asphyxiation of monkeys produced no hemorrhages, large or small. The duration of asphyxia made no difference; hemorrhages were absent from the brain of the one monkey that had been resuscitated after more than 21 minutes of asphyxia. Even monkeys asphyxiated so long that they could not be resuscitated showed no cerebral hemorrhages. On the other hand, little hemorrhages were sometimes found in the brains of asphyxiated monkeys that had been resuscitated but then for one reason or another, days or even weeks later, had difficulties in breathing that led gradually to their death. Hemorrhages of this kind must be caused by factors other than the lack of oxygen.

Premature birth is said to enhance the likelihood of cerebral hemorrhage. Traumatic delivery may also be an important cause of such hemorrhage. We observed brain hemorrhages in a monkey whose head had had to be extracted manually during a breech birth (a feet-first delivery). Human infants may be more susceptible to traumatic birth injury and brain hemorrhage than monkeys because of their larger heads. The use of drugs to strengthen uterine contractions and hasten delivery can cause bleeding from the vessels of the brain. Oxytocin administered to a gravid monkey to induce labor was responsible for hemorrhages in such deep-seated fetal brain structures as the globus pallidus.

Some neuropathologists believe swelling, or edema, of the brain is a primary cause of brain lesions. Other investigators have reported that edema of the fetal brain was induced by experimental interference with the passage of oxygen across the placenta in monkeys. Our experimental asphyxiation of monkeys during birth, however, did not result in any swelling that could be identified at any time after their resuscitation. It seems probable that edema of the brain at birth is not an important cause of brain damage.

Kernicterus is characterized by groups of nerve cells with a canary yellow color. This condition is related to high levels in the blood of the bile pigment bilirubin. A high bilirubin level (hyperbilirubinemia) is manifested by jaundice and



HYALINE MEMBRANE appears as a dark lining inside the lung sacs in this micrograph. It is widely believed the hyaline membrane causes asphyxia at birth. The author proposes that, rather than being a cause of asphyxia, the membrane is the result of asphyxia.

occurs in infants with such disorders as Rh incompatibility. Sometimes extraordinary efforts are made to ameliorate hyperbilirubinemia in human infants in the belief that the excessive amount of bilirubin can produce brain damage. We found no experimental evidence that hyperbilirubinemia per se causes the lesions that have been associated with kernicterus.

When the level of bilirubin was experimentally elevated in the blood of newborn monkeys, a marked jaundice developed, but no kernicterus. An episode of asphyxia during birth superimposed on hyperbilirubinemia did, however, bring about a full-blown kernicterus. It is true that hyperbilirubinemia is associated with the reduced ability of tissues to utilize oxygen, and that it can thus compound the metabolic disturbances caused by asphyxia or other conditions. These observations suggest that when hyperbilirubinemia is present, the emphasis should be placed less on relieving the jaundice than on avoiding or preventing asphyxia. Maneuvers aimed at eliminating or reducing excess bilirubin in blood of the fetus may only exacerbate other conditions that may give rise to asphyxia. Such maneuvers may produce the same brain damage or even worse damage but without the telltale yellow color of kernicterus.

Most of our experiments on asphyxia neonatorum in monkeys were designed with the hope of avoiding these various complicating conditions. One of our major concerns was to determine what effects asphyxia neonatorum might have on the individual as he matured. It is known that children with some forms of brain damage arising from difficulties at birth show improvement over a period of time. Credit is often given to intensive therapy, but many instances of spontaneous improvement are known.

The briefly asphyxiated infant monkeys with minimal brain damage lost their signs of neurological deficit. Even those whose brains had been severely damaged by more prolonged asphyxiation, including several that had experienced other difficulties after birth, exhibited substantial improvement in their physical condition in due course. The extent of this "recovery" was surprising because no replacement of the nerve cells destroyed by asphyxia neonatorum could be expected. Only after we had made thorough histological studies of the brains of the animals that had been allowed to reach adolescence or adulthood did the significance of the apparent recovery become clear.

Seventeen monkeys were selected for a study of changes in neurological status over a period of time. All of them had shown marked neurological deficits on the first day after resuscitation. Seven of them had turned blue after birth, and two had been in coma. None could suck, and six showed impaired swallowing. All 17 monkeys tended to be lethargic. They could not right themselves but lay on their side and made uncoordinated flailing movements of their arms and legs when they were disturbed. Normal newborn monkeys can right themselves and crawl in a few hours; a few can stand, although they are unsteady when they try to walk.

During the first week or two it was necessary to keep most of these asphyxiated monkeys in incubators in order to control their body temperature and to be able to administer oxygen on occasion. Some required nursing care around the clock. They slept most of the time but made random movements when they were handled. When they awoke, their crying was weak. Three of them had minor seizures of forelimbs and five had generalized seizures of the trunk and the extremities, accompanied in two cases by salivation and vocalization.

By the end of the first or second week the condition of most of the monkeys showed some improvement. Although they could not right themselves, they maintained a sprawling attitude when they were placed in the prone position. They did not move, however, until they had been stimulated. Then their attempts to progress forward were weak, their limb movements being uncoordinated and tremulous. They could not localize sounds. They were still quite helpless.

Some of the early neurological deficits gradually disappeared or were masked as the monkeys matured. The adjustment to handicaps began to be evident during the first month. Normal monkeys a month old are active, alert and highly emotional. They run, climb and jump, and are more advanced in many ways than human children three or four years old. The month-old asphyxiated monkeys, on the other hand, were dull, slow and generally inactive. They lacked curiosity about surrounding objects and were undisturbed by strange environments. Their motor functions were not normal. Their limb movements were imperfectly coordinated, their forelimbs often acting independently of their hindquarters. Some of the infant monkeys had marked peculiarities of locomotion. They hopped forward like a rabbit, using their hind limbs as a pivot. One monkey had such marked spasticity of the forelimbs that it used its limbs as crutches in hopping. Some of the month-old monkeys still had difficulty sucking. Seizures were no longer seen and electroencephalograms showed few abnormalities.

In most cases the functional defects

gradually became less noticeable. The daily care of one animal, however, was so burdensome that it was killed at 10 months. The rest were permitted to live until adolescence or maturity; five of them are still alive nine to 11 years after asphyxiation at birth. This is about a third of their normal life-span.

The adjustment of the monkeys to the neurological deficits of infancy reached a plateau after three or four years. The residual deficits of the surviving animals are now inadequate manual dexterity and a reduced level of spontaneous activity. The monkeys find it difficult to pick up small morsels of food and prefer to feed themselves as dogs do. They can run, climb and jump when forced, but usually they do not choose to do so. They simply do not engage in all the activities of normal rhesus monkeys. Nevertheless, casual inspection of them in their cages reveals little or nothing of an abnormal nature. This was the case in all of the monkeys that had survived for a long period, including the 12 that were killed for brain studies.

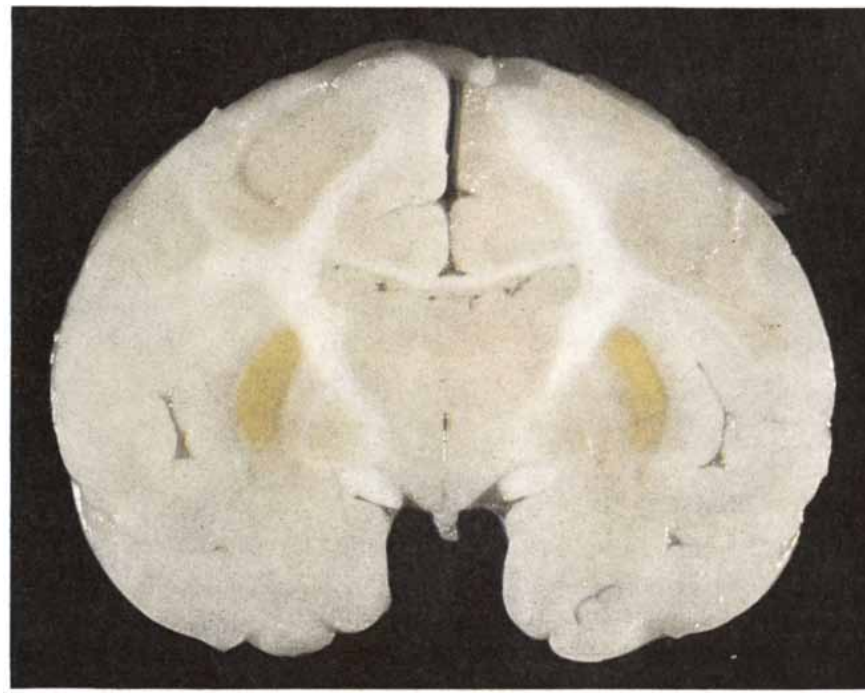
Sections of these brains showed the same pattern of lesions found in the brains of the monkeys killed a few days to a few months after resuscitation. The original lesions of asphyxia appeared as shrunken scars or even cavities. There was no evidence of structural "repair" of the brain tissue. Indeed, there was more loss than we had encountered in the brains of asphyxiated monkeys killed soon after birth. A widespread depletion of nerve-cell populations in regions that had not been affected by the initial asphyxiation had developed. This was particularly noticeable in certain regions of the cerebral cortex, but it was also encountered in parts of the thalamus, the basal ganglia and the brain stem, and in the dorsal regions of the spinal cord. The cell loss was not accompanied by scar formation, as it had been after the primary asphyxia lesions. Nerve cells of these initially intact regions simply were not there. It is probable that their disappearance from the cerebral cortex had come about because nerve cells in the thalamus had been destroyed by the asphyxia at birth and their nerve fibers, which radiate from the thalamus to the cortex, had degenerated. The nerve cells of the cortex on which these fibers had terminated atrophied and disappeared.

The monkeys that showed this secondary brain damage had been severely affected by the primary losses incurred with asphyxia neonatorum, and early in life they had exhibited symptoms comparable to human neurological disorders, including cerebral palsy. The symptoms gradually lessened, and in time most of them disappeared. (This is strikingly evident in our motion-picture records.) In view of the extensive nerve-cell loss that had been sustained by the brain it is remarkable that so few physical handicaps persisted. The main structural defects involved centers that process signals from the environment and others that control the association and integration of information. The motor elements withstood the effects of asphyxia neonatorum to a greater degree. This leads one to wonder if such functions as memory and learning were affected by the physical damage so apparent in the microscope slides.

In undertaking to answer this question Jeri A. Sechzer tested four of the surviving experimental monkeys against four similarly reared normal monkeys for their ability to execute a standard delayed-response test. The testing was done in their home cage, to the front of which a special device had been attached. Through a plastic window the monkeys could watch the experimenter place a banana-flavored food pellet in one of two closed wells. After a delay of between five and 120 seconds the window was raised and the monkey was expected to open the correct well to get the reward of food. The study clearly demonstrated a memory deficit in the monkeys eight to 10 years after asphyxia [*see illustration on page 81*].

How can these findings in monkeys be related to human infants who survive asphyxia neonatorum and initially have alarming neurological deficits? Significant data on the question are now available from the Collaborative Perinatal Research Program supported by the National Institutes of Health. Approximately 1.5 percent of all the infants who had been born on the obstetrical services of the 14 participating U.S. medical institutions were found to have neurological abnormalities at the end of their first year. If the neurological examinations had been conducted before the infants were a year old, the number with detectable deficits would undoubtedly have been much greater; for example, 21 percent of the infants in the study had low Apgar scores at birth.

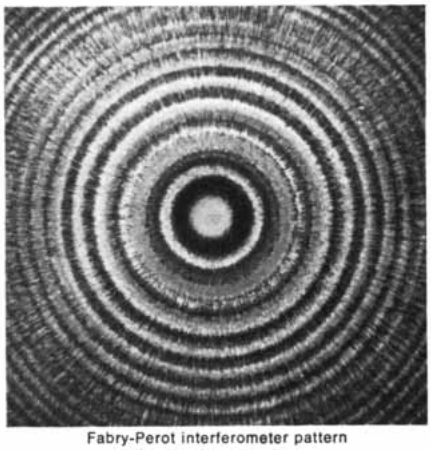
The findings were not considered to be particularly alarming because most of these children seemed to be normal by the time they were four years old. It may be wishful thinking, however, to conclude that all is well with such a child because he does not have a physical handicap. It is commonly recognized that improvement can be expected after a distressful birth. A child with a slight brain defect often appears no different from a normal child. His intelligence quotient may lie in the range considered



CELLS STAINED YELLOW, a condition called kernicterus, appear in this micrograph of tissue from monkey brain. It was thought that such staining, produced by excessive amounts of the bile pigment bilirubin in the blood, damaged brain cells. It appears, however, that only those cells that are already damaged by asphyxia at birth become stained with pigment.

"LASER LIGHT"

A SCIENTIFIC AMERICAN FILM



Fabry-Perot interferometer pattern in krypton-ion laser beam

Almost everyone has heard of lasers, but relatively few people have seen them in action. The Editors of SCIENTIFIC AMERICAN now present "LASER LIGHT," a 16-millimeter sound film about lasers: what they are, how they work, the marvelously pure and curiously scintillating light they produce, how they are being used and how they may be used in the near future. The film is in color and lasts 37½ minutes. It is now available for sale or rent.

A few highlights of the film are:

- **Computer-generated animation explaining stimulated emission and resonant optical cavities.**
- **Ripple-tank and oscilloscope demonstrations explaining the wave principles underlying laser action and holography.**
- **Holograms, their three-dimensionality dramatically evoked by the moving camera.**
- **A 600-foot, 8.8-kilowatt laser in action.**
- **Tunable lasers.**
- **A television picture transmitted by laser beam.**
- **The laser chalkline for the San Francisco Bay tunnel.**
- **Laser interferometry.**
- **Gas, solid and organic-liquid lasers.**
- **An experiment on the use of holography in a computer memory.**
- **Original musical score.**

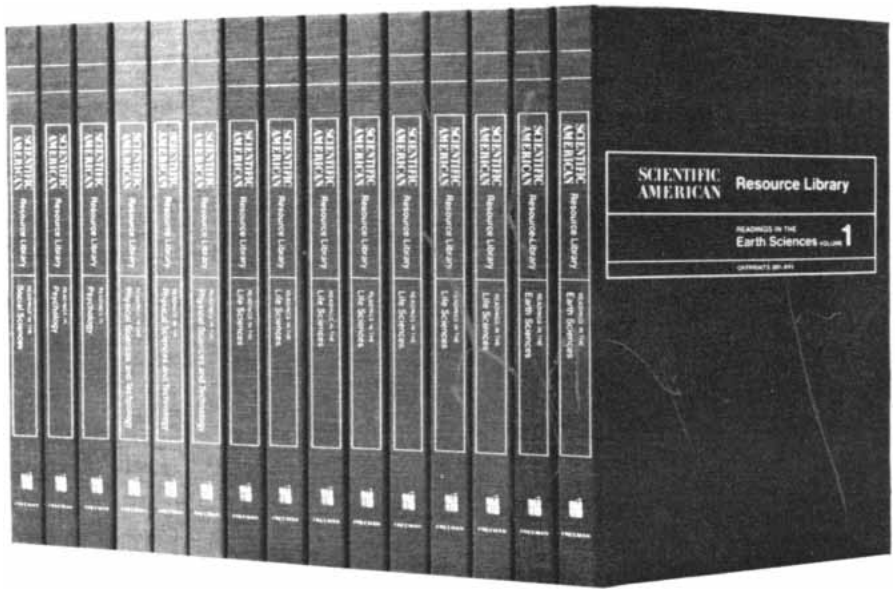
"LASER LIGHT" is recommended for general audiences with an interest in science and technology, and for use in conjunction with the teaching of physics and optics. The film is accompanied by a selection of five SCIENTIFIC AMERICAN articles on lasers and holography, written by leading authorities in these fields.

The sale price per print is $375, the rental price $37.50 for a booking of three days. If the film is purchased after rental, the rental price will be deducted. If rental booking is desired, kindly specify date. Write Motion Picture Department, SCIENTIFIC AMERICAN, 415 Madison Avenue, New York, N.Y. 10017.

normal, but one never knows how much higher it would have been if his brain had escaped damage in the uterus or during birth. The brain-damaged monkeys also overcame most of their neurological deficits at roughly comparable stages of development. The difference is that we know that the brain of a "recovered" monkey is structurally damaged, whereas we only assume on clinical grounds that the brain of a "recovered" human infant is normal. There can now be little doubt that the brain of such an infant also harbors lesions. The few postmortem studies of the brains of human infants who suffered asphyxia at birth have revealed damage similar to that sustained by the asphyxiated monkeys.

The monkey experiments described in this article have taught us that birth asphyxia lasting long enough to make resuscitation necessary always damages the brain. This could be proved, however, only by histological examination. A great many human infants have to be resuscitated at birth. We assume that their brains too have been damaged. There is reason to believe that the number of human beings in the U.S. with minimal brain damage due to asphyxia at birth is much larger than has been thought. Need this continue to be so? Perhaps it is time to reexamine current practices of childbirth with a view to avoiding conditions that give rise to asphyxia and brain damage.

AZTEC FIGURINE of Ixcuina, the goddess of childbirth, illustrates the squatting position of delivery that is observed in some primitive societies today. It may be that this position is less likely to cause asphyxia of the infant than the supine position of delivery.



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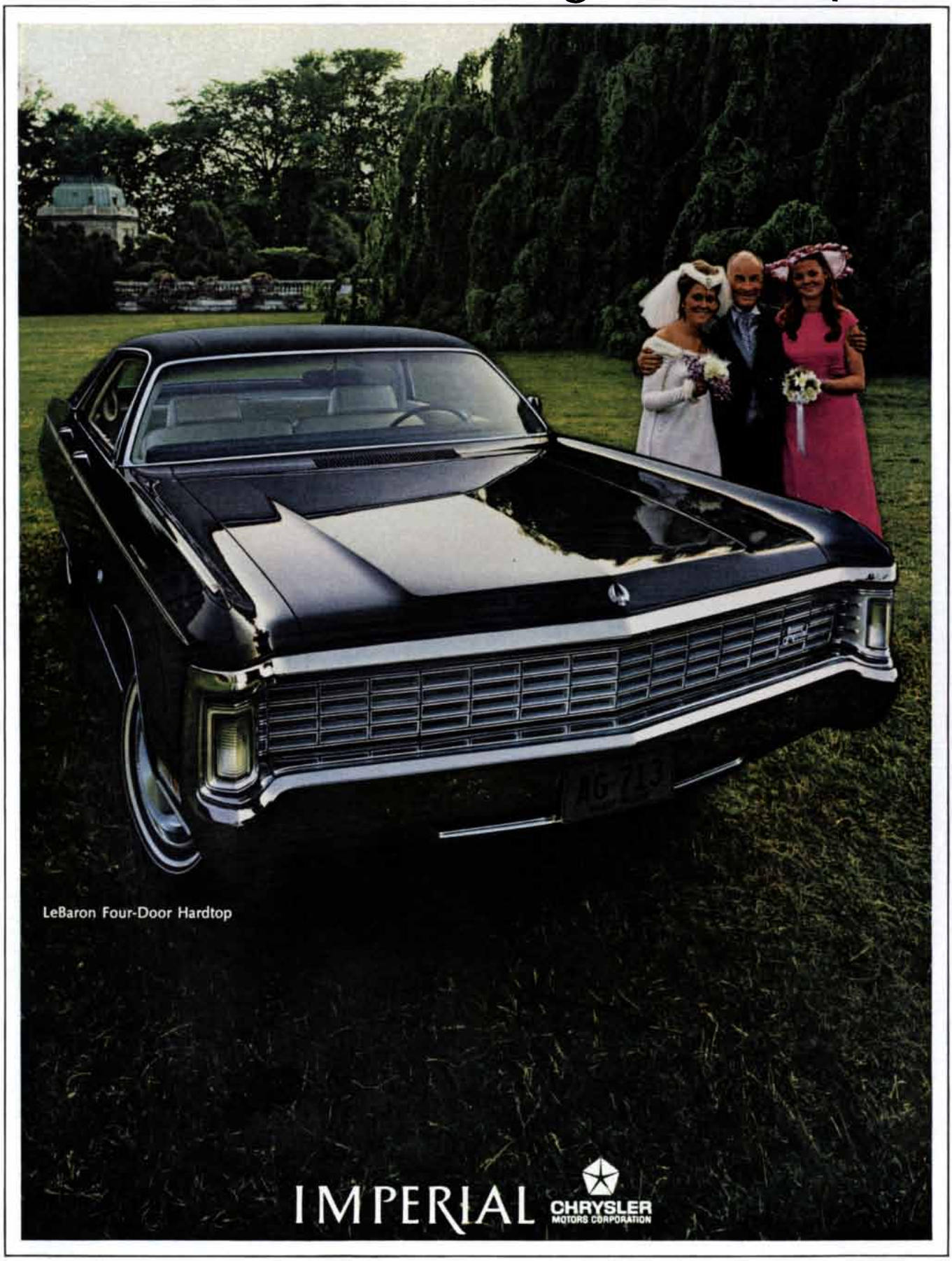
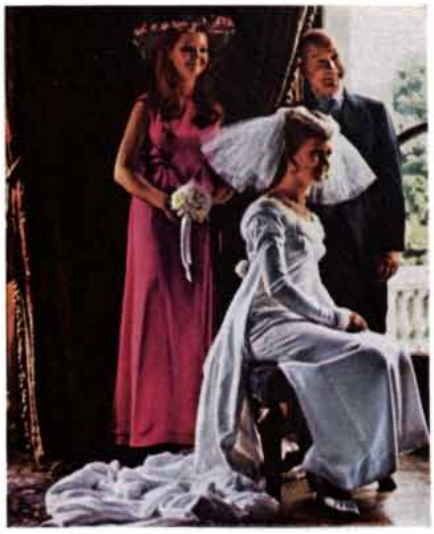


with a guide to its virtues.

A man is understandably proud of the things that please him most.



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