

CRANIAL AND INTRACRANIAL BIRTH INJURIES*

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MANY are engaged in a movement which has for its object prenatal care. Maternity centers have been established in the larger cities and they are popular for their motive appeals to all classes. The basis of their work is a two-fold desire, the protection of the mother during her pregnancy and labor and the assurance that a healthy and normal child will be brought into the world.

If the report of the Health Department¹ for the week ending March 20, 1920 is examined, it will be found that of the total number of those born—living and stillbirths—there were 3.7 per cent born dead and of those living 3.8 per cent died within the first month. These figures combined, compare closely with the figures from the Johns Hopkins clinic² which show 7 per cent of infant deaths in 10,000 labors and with the Sloane Maternity³ of 7.2 per cent in the same number of cases. The latter figures in both instances being compiled from the infant deaths from the seventh month of gestation to fourteen days after delivery.

In a series of 14,468 births, with a stillbirth rate of 3.6 per cent, J. C. Edgar⁴ found that of the 341 cases in which the cause could be determined 110 or 32 per cent had obstructed or protracted labor. McQuarrie⁵ in a small series found that the stillbirths were due in 37½ per cent of the cases to trauma.

In this paper I propose to call attention to the fact that a considerable proportion of stillbirths and early deaths are due to injury to the head of the infant and to suggest that in a few instances the lesions lend themselves to treatment that might lessen in some degree the early death rate and lower the morbidity in those infants that now survive.

Several of the earliest obstetricians recognized the significance of cranial injuries as a cause of stillbirth. Marceau in 1695 and Smellie in 1752 and Litzman in the latter part of the nineteenth century reported cases of depression and fracture of the skull in the parietal region. Rosinski,⁶ in 1893, tabulated all the cases that he could find in the literature, which proved to be 38; and he added 5 cases of his own to the discussion of this subject.

As early as 1837 Evory Kennedy⁷ called attention to the brain lesions, especially edema and hemorrhages, occurring in certain newborn and very young infants; and about 1851, Weber⁸ and in 1853 Hecker⁹ described in detail the meningeal and cortical injuries occurring at birth.

That some of these bleeding cases survived and suffered from the effects later in life was first made clear by Little.¹⁰ In 1861 he read a paper before the London Obstetrical Society entitled: *On the Influence of Abnormal Parturition, Difficult Labors, Premature Birth and Asphyxia Neonatorum on the Mental and Physical Condition of the Child Especially in Relation to Deformities*. The full title of the paper is cited because it shows the manner of

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his explanations for the paraplegias and idiocy and other brain symptoms occurring later in childhood. He gives the birth history in some 50 cases and states that added to 200 cases that had applied at his hospital for orthopedic treatment there were a great many in idiot asylums over which he had no control. He found that some of the infants had been born by the breech, some were premature, and in others it had been difficult to start respirations. He laid great stress on the fact that asphyxia would considerably increase the pressure in the cortical veins and he believed sufficient to rupture them especially in the premature. Correlated with the autopsy findings that he mentioned in his paper, he entirely established the connection between brain hemorrhage at birth and infantile spinal paralysis, now often called Little's disease.

In 1885 Sara J. McNutt¹¹ collected 10 cases of autopsies on infants dying within 5 days of birth and with the obstetric history showed that intracranial hemorrhage was a considerable factor in producing mortality in the first days of life. Her contribution is very important for the following reasons: It established in a group of cases the pathologic picture and from the point of etiology completes Little's paper. Evidence was produced that delivery by the breech might be accompanied by bleeding over the vertex as it occurred in three of her cases. Finally, the collection of such a group now assumes importance for in each of these ten cases time enough existed between birth and death for surgical intervention to have taken place and perhaps offers evidence to us some thirty-five years later, that we must move in that direction.

In 1892, Herbert Spencer¹² found in 130 autopsies in the newborn, 53 or 40.7 per cent had cerebral hemorrhage. Archibald¹³ in 1909 found 43 per cent of 74 cases with intermeningeal hemorrhage. Warwick¹⁴ in 1919 showed 50 per cent of hemorrhages in 36 deaths in infants stillborn or dying early; and our own series shows 40 per cent in 100 cases in which the skull was opened.

Assuming that the literature offers proof that cerebral injuries are not infrequent, we may turn to those papers which deal with treatment.

Kerr¹⁵ mentions the report of Boissard of a case trephined in 1877. This is the first decompression operation on the newborn. It was performed for fracture of the parietal bone with intracranial pressure symptoms, and it was a success.

In 1901, Kerr¹⁶ suggested a method of treatment for the spoon-shaped depressions occurring in the frontal and parietal regions. The skull was squeezed in the longitudinal direction, thus increasing it in the lateral dimension and perhaps at the same time producing more pressure within. He mentions three successes by this method. As a surgical procedure it is illogical, for the danger from such an injury is intracranial pressure and hemorrhage, and the depression may be accompanied by fracture—conditions that would not be helped by further increase of pressure within the skull.

Cushing¹⁷ in 1905, advocated the adoption of the same principles of treatment in the cerebral bleeding of the newborn that are made use of in the adult. He reported four cases with definite symptoms in which he decompressed the skull by a large osteoplastic flap, which was turned back in the parietal region. Two of the cases recovered and two died. The history of these babies together with the two autopsy reports forms a foundation for future work in this subject.

Tweedy¹⁸ in 1908, advised the treatment which was in vogue in the Dublin Maternity for the depressions occurring about the coronal suture. Apparently his advice is meant to apply only to those depressions which occur without immediate symptoms of intracranial pressure. He makes an incision over the dent and boring through the bone with the end of a vulsellum forceps, inserts the sharp end under the bone and pulls it up, thus reinverting it. Kosmak³⁰ has recently devised an instrument for use in this procedure.

ANATOMIC AND OBSTETRIC CONSIDERATIONS

Little made it clear that some of the children showing lesions attributed to injuries at birth were breech presentations, and that there were other factors beside head pressure in difficult labors. He pointed out that vessels in the cortex and other parts of the body are especially fragile and quoted Weber and Hecker as testifying to the frequency of minute hemorrhages in other organs besides the brain in stillborn infants. The congestion from asphyxia alone he believed was enough to rupture cortical vessels in full term children.

It is a fact noted by many that these stillbirths have hemorrhages in other viscera. Neglecting the explanation of congestion, Green¹⁹ and also Warwick stated their belief that these cases represented deaths from a condition identical with that known in the first week as "hemorrhage of the newborn." This explanation is not in accord with our theories concerning the disease and it seems a little far-fetched, when in nearly all of these cases there is an asphyxia that dams back the blood in the veins and increases the pressure to an extent that would produce exudation.

Cushing agrees with Little that asphyxia neonatorum may lead to rupture of the cerebral vessels, just as it sometimes occurs in asphyxia from the spasms of whooping cough. McNutt's three breech cases with cerebral hemorrhage had the extravasation only over the vertex. While this is a significant fact as regards asphyxia, of course it is not conclusive, for the bleeding in this position might be due to concussion from the contact of the head with the pelvic bones in rapid withdrawal.

In hemorrhages occurring in the small and premature, we must recall that the cranial bones are poorly developed and that there are wide gaps at the suture lines. On first thought it would seem that there was little probability of cortical hemorrhage, for the cavity is more distensible; however with these bones loosely joined they are more easily made to overlap and thus cut the veins leading to the longitudinal or lateral sinuses, or even to injure the sinuses themselves. Virchow first pointed out that the veins of the cortex have little support as they enter the sinuses. Cushing also dilates on this anatomic condition. If these veins are unprotected for even a minute distance as they empty their current into the larger channels, it is evident that they may very easily be ruptured by marked moulding of the head.

In cases where the pelvis is flattened, the symphysis being 5 cm. deep in front and the sacrum 12 cm. in the back, the head cannot advance uniformly through the cavity. Usually the anterior parietal advances while the posterior bone is retarded. As a consequence the lower anterior bone moulds over the

one on the opposite side that is engaged against the sacrum. If the posterior bone advances first, the moulding becomes extreme. Edgar²⁰ says: "Presentation by the posterior parietal bone is serious because the head is wedged on the symphysis pubis. * * * Great pressure is exerted on the posterior bone by the sacrum, causing a depression in the bone. Sometimes this depression is spoon-shaped. It is quite likely that the brain has been injured." (Fig. 1.)

The sharp edges of the bones undercut the vein tendrils as they enter the sinus on the opposite side of the midline. Such a hemorrhage would be subdural, but might by dissection become subarachnoidal and circulate with the cerebrospinal fluid over the medulla and into the cord. As so many of the autopsies show blood in these places, it seems probable that this accident due to synclitism and moulding, in a flat pelvis, is not infrequent.

Fracture of the skull producing hemorrhage usually means the rupture

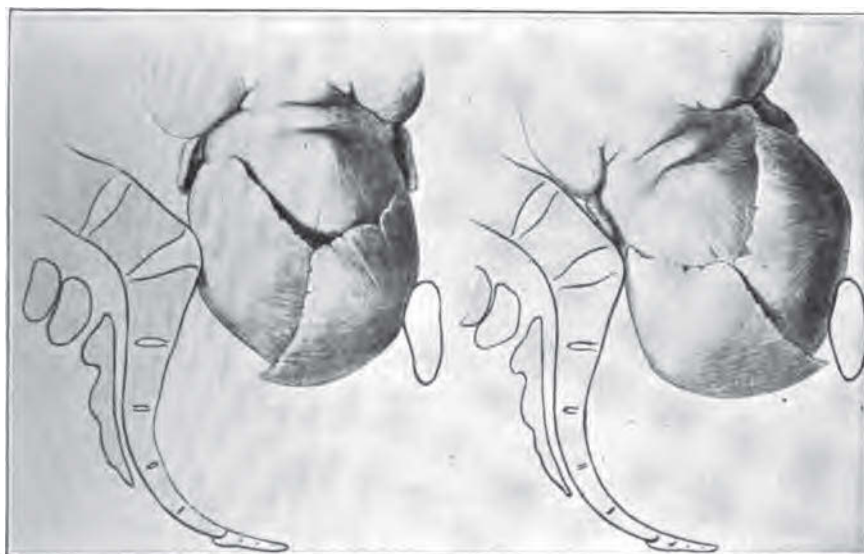


Fig. 1.—Synclitism with overlapping of the parietal bones. Apt to occur in flat pelvis and may lead to rupture of the cortical veins as they enter the longitudinal sinus. (From Bumm, Grundriss zum Studium der Geburtshilfe.)

of a meningeal vessel. This condition seems to be rare, perhaps because of the loose attachment of the dura to the bone in the newborn. Poor application of the forceps or brutal force are the two conditions that might give rise to a crushing lesion such as is pictured by Rosinski. Of course, the close locking of the blades and traction against an obstacle would cause the parietal bones to overlap and the hemorrhage might be produced as outlined above.

The bleeding from the surface of the cortex is often held beneath the pia and may produce considerable damage even when it is of slight extent, if it is located near the cortical centers. (Figs. 2 and 3.)

Hemorrhage into the ventricles may occur from rupture of the choroid plexus. It occasionally occurs without bleeding elsewhere in the brain. It was present in one of our cases, where the delivery was by Cesarean section, and Osler found it in a case of an unborn child of a woman dead from typhoid.

In Spencer's series there were 15 children delivered by the forceps. Of 12 that were alive when the forceps were applied, there were 11 that had intermeningeal hemorrhage and one with intercerebral bleeding. Twenty of his 53 cases were delivered by breech extraction, and there were 13 that were normal vertex presentations.

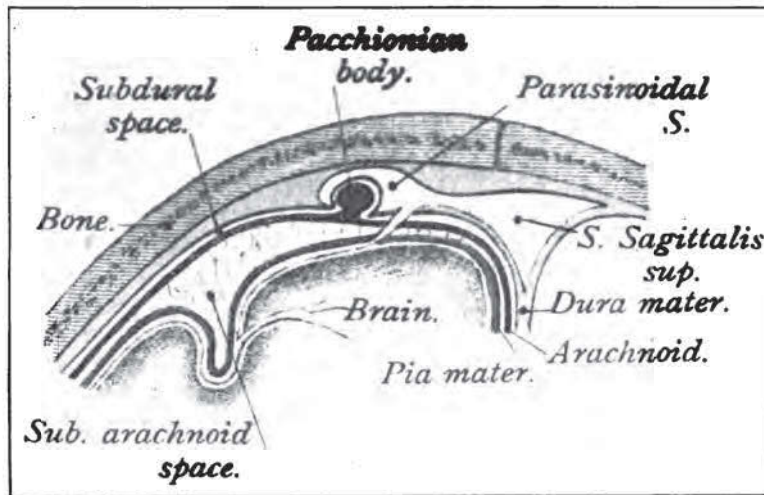


Fig. 2.—To show the subarachnoid space where the bleeding often occurs. (From J. Ryland Whitaker: *Anatomy of the Brain and Spinal Cord*.)

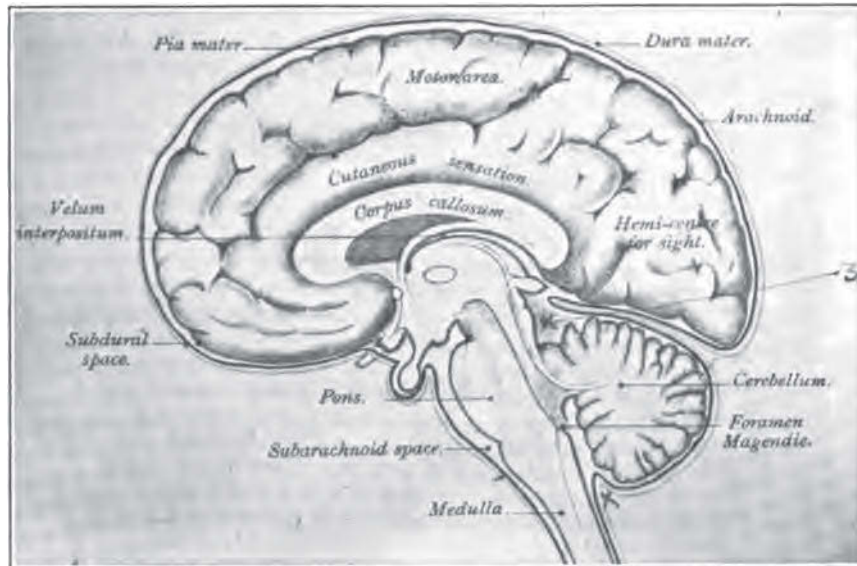


Fig. 3.—To show the relationship of the arachnoid at the base of the brain and to indicate the location where considerable blood may collect beneath the tentorium. (From J. Ryland Whitaker: *Anatomy of the Brain and Spinal Cord*.)

Margaret Warwick's series of 18 cases from the University of Minnesota Hospital are very accurately described. They are particularly interesting because 16 were born alive and of these, 12 were normal births with spontaneous

TABLE I
CLASSIFICATION OF FORTY CASES OF CEREBRAL HEMORRHAGE
AUTOPSIES FROM THE MANHATTAN MATERNITY HOSPITAL

FORCEPS DELIVERIES						
HOSPIT. NO.	STILL BIRTH	AGE AT DEATH	LOCATION	HEMORRHAGE IN VISCERA	ASPHYXIA	NOTES
62	*		Cerebral	.....	yes	Median
98	*		Diffuse	Liver, lungs	yes	High
106	*		Diffuse over cortex and in Vent.		yes	High
111	*		Diffuse over cortex	Punctate lungs,	yes	.....
193	*		Over temporal region	lungs, heart, kidney.	yes	.....
198	*	36 hrs.	Over vert. occip. and frontal	viscera, punctate	yes	.....
219	*		Diffuse in pia; marked over cerebellum	thymus, heart, lung	yes	.....
250	*	5 days	Extra and subdural and cerebellar	.....		High
251	*		Dural right side	.....	yes	Median
BREECH DELIVERIES						
67	*		Diffuse cerebral	.....	yes	Version
74	*		Diffuse cerebral	.....	yes	
73	*		Diffuse Marked occip. lobe	.....	yes	
99	*		Diffuse over entire cortex	.....	yes	
102	*		Diffuse meningeal	lungs, thymus	yes	
134	*		Over both temp. lobes	.....	yes	Premature
192	*		Multiple base and in pia	viscera	yes	
152	*		Occipital region	viscera	yes	
93	*		Diffuse in pia	.....	yes	Version
141	*		Cerebral multiple	.....	yes	Version
151	*	14 hrs.	Epidural over parietal. Diffuse in parietal lobe	viscera		Version
NORMAL DELIVERIES						
64	*	20 min.	Diffuse over cortex	Punctate viscera		Dry labor
88	*		Diffuse cerebral	Punctate lungs	yes	
101	*	2 days	Diffuse cerebral	.....	
117	*	1 day	Diffuse in pia	heart, thymus		Premature
126	*		Diffuse cerebral	lung, thymus	yes	
133	*		Diffuse in cortex	.....	yes	Premature
158	*		Diffuse, rupt. long. sinus	lungs, liver, etc.		Macerated
171	*		Diffuse, espec. right parietal	.....	
175	*		Meninges and ventricles	.....		Syphilis
196	*		Lateral ventricle	Punctate viscera	yes	Dry labor
191	*	4 days	Diffuse over occip. and parietal	“ both lungs		Precipitate
181	*	36 hrs.	Diffuse. Thrombosis sinuses	in mucous memb.		
200	*		Diffuse, pia-arachnoid	viscera	yes	
223	*	3 days	Diffuse, espec. over parietal	punctate lungs		
215	*		Diffuse, espec. occip. region	.....	yes	
234	*		Diffuse pia-arachnoid	lungs, liver	yes	
236	*	3 hrs.	Diffuse pia-arachnoid espec. over r. occip. parietal	lungs, thymus		
CESAREAN SECTION						
66	*		Both lateral ventricles		yes	
DELIVERY NOT KNOWN						
162	*		Hemorrhage in cerebellum	punctate lungs		
231	*		Diffuse parietal	viscera	yes	

establishment of respiration. There was only one infant delivered by forceps. Six of the hemorrhages were over one hemisphere. This finding upholds Cushing's belief that the hemorrhage is frequently limited to one side. There were 7 cases with the bleeding over the cerebrum and cerebellum and one case had, in addition, bleeding into the ventricles. There were two cases that had only dural bleeding and 2 with bleeding into the ventricles only.

In reviewing the Manhattan Maternity autopsy records in the last 185 autopsies, there were 100 in which the skull was opened and definite mention made of the findings. Of the 85 in which the head was not opened, 35 were so macerated or poorly preserved that it was deemed futile to proceed, and of the remainder it was apparently considered unnecessary to examine the brain because of such gross abnormalities found in other organs.

In 100 cases, dating from 1914, there were 40 cases with cerebral hemorrhage. There were but 10 that were not stillborn. One case lived 20 minutes, one 30 minutes, one three hours, and the others from 14 hours to 4 days. It is of note that of the babies that lived only 2 were forceps deliveries. Two were premature and 5 were normal births. In the entire series 9 were forceps, 11 were breech extractions, five of these being preceded by version; one was a Cesarean and 17 were normal deliveries. There were 2 cases in which the histories could not be found.

The hemorrhage in 18 cases was described as diffuse, and I think in most instances this meant over the cerebrum; 11 were noted as being especially marked under one bone; 2 were diffuse and in the ventricles, 2 were in the ventricles alone; 1 was a diffuse meningeal hemorrhage with thrombosis of the sinus; 2 were in the cerebellum; 2 were in the pia and 2 were in the dura.

A REPORT OF FIVE RECENT CASES OF CRANIAL AND INTRACRANIAL INJURY

CASE 1.—Female child of B. K., born on the Bellevue service Oct. 5, 1919. The mother had a flat pelvis and had been in labor two days when brought to the hospital. Forceps had been applied to the floating head. A version and breech extraction was performed and the operator was assisted by the house-surgeon pushing the head into the pelvis from above. The delivery proved to be remarkably easy and the child passed through the pelvis with great rapidity. On delivery a marked depression, of the spoon-shaped variety, was present in the left parietal bone, a little in front of and above the eminence. There were no signs of intracranial injury. As this depression was almost over the center of the Rolandic area, where scarring or injury would almost certainly be followed by paralysis, it was decided to elevate the bone. Eight hours after delivery an incision was made for a distance of 5 cm. directly over the dent, and the pericranium was incised. With the sharp end of a vulsellum forceps, by a drilling action a hole was bored in the bone. There was some compression of the cranial contents, for the dura was in close contact with the bone and it was punctured. Clear fluid came out under pressure. The hook was inserted under the bone and on lifting, the bone assumed its normal shape at once with a spring-like action. The pericranium was repaired with catgut and the skin with silkworm-gut. The baby showed no reaction and was normal until the fifth day when the skin wound broke down. The resulting wound was washed out daily and became at once a clean granulating surface. About this time a series of infections occurred in the nursery and later caused the death of a number of infants from a specific organism—the *Streptococcus hemolyticus*. On

the eleventh day, when the wound was nearly healed, the baby had a rise of temperature and died on the fourteenth day after delivery. On the day of its death a blood culture showed the organism mentioned. (Fig. 4.)

CASE 2.—Infant of N. B., born on the Bellevue service Oct. 18, 1919. The baby presented in left occiput posterior position and was delivered by forceps using the Scanzoni procedure. As the head reached the outlet there was some difficulty in securing rotation. On delivery the left frontal bone had a spoon-shaped depression. Although there were no signs of intracranial injury the depression was raised by the method of Tweedy as described above. The wound healed by primary intention and the child gained weight in the usual manner. It was discharged with its mother on the tenth day.



Fig. 4.—Spoon-shaped depression in the left parietal bone produced by contact of the promontory of the sacrum with the after-coming head in breech delivery. (Drawing.)



Fig. 5.—Spoon-shaped depression of the left frontal bone produced by contact with the spine of the ischium in instrumental rotation of a head deep on the pelvis. (Drawing.)

As to the seriousness of spoon-shaped and other dents of the skull, the only available statistics except for occasional cases are those of Schroeder.²¹ In 65 cases 34 per cent were stillborn, 15 per cent died and 50 per cent remained alive. In cases of meningeal injury the symptoms, being mainly those of increased pressure, are frequently delayed and in some instances do not appear until the second or third day. Case 4 will serve to illustrate this point. (Fig. 5.)

CASE 3.—Intracranial injury. Male child of J. M., born on the Manhattan Maternity service March 1, 1920. Weight at birth 9 pounds 8 ounces. Forceps were applied for an anterior position of the occiput well engaged in the pelvis. The procedure was difficult, and even after the birth of the head the shoulder delivery was delayed and considerable traction was made on the neck of the child. Respirations were started by the Prochonik method of resuscitation. The child's face became swollen on the right side but the infant was sent to the ward without evidence of any other injury. In the morning some 12 hours later, it was found that there was a right facial and a right arm paralysis. The baby did not cry and could not be made to cry although its respirations were normal. It could not swallow or nurse and fluid placed in its throat with a dropper returned at once through the mouth. There was marked tension in the fontanelle. There was a slight groove-shaped depression on the posterior part of the left parietal bone above the eminence.

While at first glance it seemed that the child had a peripheral facial paralysis and an Erb's arm palsy, the above symptoms indicated that there was decided intracranial pressure. On close observation it was seen that the eye of the child remained closed and although there was some swelling of the upper part of the face it seemed as if this paralysis was due to a cortical lesion. The reflexes of the arm were not only present, but they were exaggerated. This was markedly so of the supinator reflex. The legs were not affected so far as could be determined.

The case was seen in consultation with Dr. A. M. Wright and he verified the above findings. He stated his belief that the skull should be opened to



Fig. 6.—Operative site, after healing.

relieve the symptoms of intracranial pressure, and he felt that the focal symptoms present pointed to a hemorrhage in the middle of the left Rolandic area.

The cranium was opened by a large osteoplastic flap of the left parietal bone. The depression in the bone was disregarded and the angle of the Rolandic area was laid out by folding a paper to $67\frac{1}{2}^{\circ}$ and marked on the shaved skull. Hemorrhage was controlled by a catheter tied around the head just above the eyes. In making the incision into the bone the knife entered the coronal suture and punctured the dura. Great difficulty was encountered in cutting the bone with scissors, as the blades would separate. After a considerable opening had been made the bone was lifted and the remainder of the bone incision was comparatively easy. In about the center of the dura, then

exposed, there was a dark area. The dura was incised and at once there was a decided hernia of the brain, the cortex rising well above the bone. About the middle of the exposed area and as far as could be judged at the center of the fissure of Rolando there was a clot about 2 by 3 cm. lying directly over the cortex. This was washed with warm saline. The question arose as to the necessity for decompressing the opposite side in order to reduce the hernia. Irrigation with the warm salt solution and the equalization of the pressure gradually caused the brain to recede somewhat. The dura could not be united so the entire flap was replaced and the skin and pericranium were brought into apposition with many silkworm-gut stitches. The posterior and upper



Fig. 7.—Twenty-five days after operation. Note the raised area in the skull, the facial paralysis still remaining and the typical arm position.

portion of the flap was well above the level of the rest of the bone. The infant had only a small amount of ether by the drop method.

The child was fed by gavage, and after a few days the greater part of the facial paralysis cleared, he cried normally, and was able to nurse. Gradually some motion and strength was evidenced in the flexor group of muscles of the forearm, which later became spastic. The child lost over a pound in weight during the first days, but gradually gained a little. The wound healed by primary intention except for one stitch from which a little clear serum exuded on the tenth day. This healed promptly. (Fig. 6.)

The picture presented (Fig. 7) was taken on the twenty-fifth day after operation. At discharge on the thirtieth day, the upper arm showed a typical paralysis of the Erb type with all reflexes absent. On crying, the drooping of the right angle of the mouth showed that the facial paralysis had not entirely cleared.

The weight of the child was stationary at 8 pounds, 5 ounces, and it was necessary to put it on a formula, as the mother had but little milk.

There was a hard scar-like induration in the sternomastoid muscle of the left side. This induration was first apparent about 20 days after birth. The child will be followed carefully to watch its development. (Figs. 6 and 7.)

CASE 4.—Illustrating spoon-shaped depression with fracture and intracranial injury. Infant McC., born at the Manhattan Maternity, February, 1920. This case was delivered by the forceps for an occiput posterior position. At birth there was some flattening of the right parietal bone, but this was obscured within an hour by a well marked pericranial hemorrhage of the type known as cephalhematoma. The baby had a sighing type of respiration and could not swallow or nurse. On the second day it had tense fontanelle and a peculiar weak cry, which is common with cerebral irritation. There were no localizing paralysis, but on the fourth day it developed convulsions and died on the following day. Autopsy showed a fracture beneath the spoon-shaped dent with rupture of a small branch of the middle meningeal. There was also subarachnoidal bleeding and some blood beneath the tentorium.

This case is very interesting, for if it had been operated by the method of Tweedy, as were the first two cases in this series, it would not have been helped. Here it was evidently necessary to decompress the skull to relieve the pressure. This case antedated Case 3 in which the decompression was done, and the study of its history and autopsy findings opened our minds to the necessity for action.

CASE 5.—Infant McA., stillborn on the Manhattan service March 14, 1920. The head advanced to midpelvis in a right posterior position and then forceps were applied. At birth the child did not breathe, but the heart beat strongly for 20 minutes. The usual methods of resuscitation were not successful in starting respirations. On autopsy there was found a hemorrhage within the dura of considerable extent that had found its way over the temporal and posterior fossæ, and some blood was also found on the right side and beneath the tentorium cerebelli. There was no subarachnoidal or cortical hemorrhage.

This case is cited because it is so typical of forceps trauma and gives rise to speculation as to the advantages to be gained from rapid decompression through the coronal suture line while respiratory efforts are continued by means of mechanical apparatus.

SUMMARY AND CONCLUSION

The results from decompression operations of the large osteoplastic flap type are not good. Cushing²² operated nine cases with but four successes. With the exception of our case all other cases have been fatal. Taylor²³ reported 2; Seitz,²⁴ 1 (?); 2 by F. T. Murphy²⁵ and one each by Ballock²⁶ and Hubbard.²⁷ There are, however, four successful cases of decompression by another method. Simmons described a method patterned after that used by Boissard for lifting the bone in dents about the coronal suture. The coronal suture line is incised one and one-half inches from the midline and the dura opened for $\frac{3}{4}$ of an inch and a rubber tissue drain inserted. Two such operations were done by Simmons,²⁸ one by F. T. Murphy and one by Green.²⁹ There

are no others recorded. There are two theoretical disadvantages: The opening of the suture line is apt to be accompanied by hemorrhage and injury to the brain substance, for the dura is intimately connected with the bone at this location. The drainage is not apt to be good, for the bones close together and effectually stop the opening. A subtemporal opening would seem to have the same advantages here as exist in the openings in older children. The Tweedy procedure without lifting a button of bone to ascertain what injury lies beneath is a makeshift as our Case 4 would demonstrate.

There is a large field for investigation and constructive work in the care of the newborn presenting meningeal symptoms. Before anything may be done for the stillborn child with the pulsating heart, a great deal of educational work must intervene. However, it seems that (as Meare and Taylor indicated) any method of resuscitation that notably increases the pressure in the cerebral veins, and those are the very methods that most of us use, should be discontinued. Mechanical respiratory apparatus, which we can trust to deliver air and withdraw the carbon dioxide, must be developed.

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