The relationship of compensated to decompensated hydrocephalus in the cat

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The effects of removal of the calvaria and excision of the dura on the development of hydrocephalus was studied in adult cats made hydrocephalic by an intracisternal injection of kaolin. In some animals, the calvaria was removed prior to the induction of experimental hydrocephalus, and in others when the hydrocephalus was compensated. In both groups of cats, the results were similar. Ventricular dilatation was massive, often leaving a cortical mantle less than 1 mm thick. A mean ventricular volume measured in 17 cats was 16.9 ml. Cerebrospinal fluid turnover measured during steady-state ventricular perfusion showed significant increases in formation and decreases in absorption of spinal fluid when compared to that in hydrocephalic cats with intact skulls.

KEY WORDS experimental feline hydrocephalus · intracisternal kaolin · compensated hydrocephalus · craniectomy

We have described experimental obstructive hydrocephalus induced in adult cats by the intracisternal injection of kaolin. Kaolin caused a severe aseptic meningitis adjacent to the injection site which obstructed the outlets of the fourth ventricle and obliterated the cisterna magna. Subsequently, there was an increase in intraventricular pressure, and hydrocephalus evolved. Within 4 to 7 days after kaolin, characteristic changes in cerebrospinal fluid (CSF) turnover occurred in these acute hydrocephalic cats. The most significant of these was a sixfold decrease in CSF absorption which resulted in only slightly enlarged ventricles.

Cats recovering from this stage were studied at 21 days or more after intracisternal kaolin. Results of CSF turnover studies in these now chronic hydrocephalic cats demonstrated a decrease in intraventricular pressure, a marked increase in CSF absorptive capacity, a twofold increase in ventricular volume, and a CSF formation rate which was similar to that measured in the acute hydrocephalic cat. It was concluded that the transition from acute to chronic hydrocephalus was accompanied by the development of transventricular absorption as an alternate CSF absorption pathway. These results also suggested that transventricular absorption limited the extent to which the ventricles dilated.

Despite complete obstruction of the spinal fluid circulation, kaolin-induced, adult, feline hydrocephalus became compensated or arrested in approximately 3 weeks. This is unlike human neonatal hydroceph-
Decompensation of hydrocephalus in the cat

alas where a CSF-obstructing lesion more often leads to relentlessly progressive hydrocephalus.

Thus, it seemed likely that the skull (open sutures and freely expansile, or closed sutures) and dura influence the development of hydrocephalus. It was hypothesized that in the adult cat, compensated kaolin hydrocephalus could be converted to progressive hydrocephalus if the calvaria was removed and the brain permitted to expand. Moreover, if the calvaria was removed prior to the injection of kaolin, the hydrocephalus would be progressive and not become compensated. In the series of experiments now being reported, the influence of craniectomy and excision of the dura on the hydrocephalic process was evaluated with respect to CSF turnover and ventricular size. In some experiments the calvaria was removed prior to the induction of hydrocephalus, and in others when the hydrocephalus was compensated. We have already reported that the mean ventricular pressure measured in 12 compensated hydrocephalic cats was $3.7 \pm 1.1$ (mean $\pm$ SE), which was well within the normal range; the control evidence was used for comparison with the present results.

Materials and Methods

Twenty-two cats were made hydrocephalic by the intracisternal injection of 125 to 175 mg of kaolin. In 11 animals craniectomy was performed prior to the injection of kaolin and in 11 others the procedures were reversed, craniectomy being performed 3 weeks to 6 months after the injection.

The craniectomy was performed through a midline skin incision. The temporalis muscles were reflected laterally and the part of the skull between the coronal and lambdoid sutures and extending laterally to the floor of the middle fossa was removed. The exposed dura except for the sagittal sinus was excised. The incision was closed by the reapproximation of the muscle and skin in layers.

At various intervals after the last procedure, CSF formation, absorption, and ventricular volume were measured by perfusion of the ventricular system under pentobarbital anesthesia from one lateral ventricle to the other with artificial CSF. Similar coordinates on the stereotaxic apparatus were used, and the frequently ballooning ventricles were penetrated by cannulas through small incisions in the skin. The entrance sites of the cannulas were sealed with a tissue adhesive. CSF formation and absorption rates and ventricular volumes were calculated from measurements made during steady-state perfusion according to Heisey, et al., and Pappenheimer, et al. At the end of each experiment, a 1% solution of Evans blue dye was perfused through the system. The animals were killed by intravenous potassium chloride. They were decapitated and the heads dropped into a slurry of dry ice and alcohol and sliced on a band saw in 1 cm thick coronal sections.

Results

The effect of kaolin after craniectomy in most of the animals was apparent within 24 hours. The brain became tense and began to bulge through at the operative site. Within 2 to 3 weeks the brain was often transformed into a thin-walled fluid-containing sac. In the group of cats injected with kaolin prior to craniectomy, the subsequent rates and severity of the developing hydrocephalus were similar. The effects of kaolin alone, and together with the removal of a portion of the skull on the ventricular size are compared in Fig. 1; craniectomy without kaolin (not shown) did not affect normal ventricles. The massive ventricular dilatation measured in this cat was 20.3 ml. Due to the loss of gray and white matter, the cortical mantle in some areas was reduced to 1 mm thickness. In two cats destruction of the midline structures reduced the lateral and third ventricle to one large compartment.

A total of 22 cats was used in these experiments (Table 1). In 17 cats a mean ventricular volume of 16.9 was measured. An increase in ventricular volume of more than 8 ml was considered significant. The ventricular volume in a normal cat is less than 1 ml.

The results of the CSF turnover studies can also be seen in Table 1. In 15 animals (regardless of the sequence of the kaolin
FIG. 1. Hydrocephalic cat. *Left:* Coronal section with a portion of the skull removed made at the level of the perfusion cannulas so that a small amount of dye leaked out to the surrounding tissue when the cannulas were removed. Preparation was cut and photographed while frozen. Huge ventricles were perfused with Evans blue dye just prior to intravenous potassium chloride. X 0.9. *Right:* Comparable section made under similar conditions, but from a perfused hydrocephalic cat with an intact skull.

injection and craniectomy), the mean rate of CSF absorption measured during steady-state perfusion at approximately 20 cm H₂O pressure was 0.0208 ml/min. The mean rate of formation in these animals was 0.0134 ml/min. The rate of CSF formation in the present experiments was 40% greater while the CSF absorption rate was 50% less than that obtained previously in chronic hydrocephalic cats with intact skulls.² The significant differences in CSF turnover rates measured in both groups of hydrocephalic cats must still be evaluated with regard to steady-state perfusion. With ventricles having volumes as large as 30 ml, the rate of perfusion and uniform mixing are critical in determining the steady state and calculating CSF turnover rates.

**Discussion**

From the present study, it is obvious that the unsupported brain does not possess sufficient elastic properties to resist deformation from increased intraventricular pressure when the normal CSF circulation is obstructed. Consequently, the ventricles expand through the skull defect and both gray and white matter stretches and thins.

The results from the data on CSF absorption measured during perfusion at a mean pressure of 20 cm H₂O suggest that in these intact animals an elevated CSF pressure was necessary to absorb all of the CSF produced. The mean opening intraventricular pressure measured as the perfusion needle penetrated the ventricles of 14 cats was 11.1 cm H₂O (range, 5 to 23 cm H₂O), or about twice that recorded previously in chronic hydrocephalic cats with an intact skull.³

The massive ventricular enlargement, some four- to fivefold greater than that noted earlier,³ may result from the inability of the animal to establish sufficient transventricular absorption, or to a decrease in

**TABLE 1**

| Effect of craniectomy and excision of dura on CSF turnover and ventricular volume in kaolin-induced hydrocephalic cats (mean values ± SE) |
|---|---|---|---|---|
| No. of Cats | Distribution Vol. (ml) | Absorption Rate (ml/min) | Formation Rate (ml/min) | Perfusion Pressure (cm H₂O) |
| 17 | 16.9 ± 1.8 | 0.0208 ± 0.0030 | 0.0134 ± 0.0014 | 20.1 ± 1.2 |
| (range) | (9.1 ± 31.3) |

Decompensation of hydrocephalus in the cat

transventricular absorption of CSF in those hydrocephalic cats receiving kaolin before the craniectomy. After craniectomy, elevated intraventricular pressure may result in a decrease, rather than an increase in CSF absorption rates. This may be due to changes in regional blood flow in brain tissue due to the relatively greater effect of pressure on the periventricular venous circulation.

This experimental model can probably best be compared to neonatal hydrocephalus in animal or man. With open cranial sutures and an expansile skull, untreated hydrocephalus usually results in extremely large ventricles. A similar situation occurs in adult cats when a large portion of the skull is removed either before or after the intracisternal injection of kaolin. In the former group, the hydrocephalus is relentlessly progressive, showing no tendency to arrest. In the latter group, arrested hydrocephalus is converted to progressive hydrocephalus of similar proportions.

It may be relevant to note that the occurrence of spontaneous arrested hydrocephalus in humans is usually between 9 and 24 months. At this time, there is some fibrous union of the sutures and under these conditions a sustained increase in intraventricular pressure may result in the development of alternative absorptive pathways.

The decomposition of normal pressure hydrocephalus following removal of a portion of the skull of kaolin hydrocephalic cats demonstrates the rather precarious equilibrium between CSF formation and absorption in these animals.

References


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