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Thomas Vullo, Rene Manzo, Daniel G. Gomez, Michael D. F. Deck, and Patrick T. Cahill

Summary: Within 3 hours of induction of acute hydrocephalus in a canine model, lateral ventricular CSF pressure increased from an initial average of 14.6 ± 2.8 cm H_2O to 40.2 ± 5.7 cm H_2O. Ventricular volumes, as measured from MR images, increased 1.45 ± 0.94 cm³, 1.92 ± 0.82 cm³, and 2.24 ± 0.60 cm³ after 6, 24, and 48 hours, of hydrocephalus, respectively. This canine model was reliable and consistent with clinical conditions.

Acute hydrocephalus can result from inflammatory disease, but it is more commonly due to subarachnoid hemorrhage (1). Changes in ventricular pressure and volume that occur in the early stages of hydrocephalus are of major concern. Previous investigations have been limited (2–4). Milhorat (2) induced acute hydrocephalus in 230 rhesus monkeys by inflating a balloon catheter in the fourth ventricle. Diggs et al (3) studied four primates, but only one at four different time periods; and Drake et al (4) induced hydrocephalus in three dogs, which resulted in the death of one preoperatively. Changes in ventricular volume were measured by MR imaging at 2 days in one animal and at 7 days in a second.

To more fully evaluate acute hydrocephalus in vivo, we introduced Silastic (3 mL polysiloxane polymer, 2.5 mL dimethyl polysiloxane, and three drops catalyst stannous octoate; Dow Corning, Midland, MI) into the fourth ventricle of 15 canines. Increases in lateral ventricular pressure were measured and MR studies were performed to quantify changes in lateral ventricular volume.

Technique

A total of 15 beagle-type canines were used in this study. All animal procedures were approved by our Institutional Animal Care and Use Committee. The dogs were anesthetized with intravenous pentobarbital and intubated. Baseline transverse and sagittal MR images (750/20 [TR/TE]; section thickness, 2.0 mm; intraplaner resolution, 0.5 mm) were initially acquired at 2.0 T. The animal's head was then immobilized in a stereotactic apparatus (David Kopf Instruments, Tujunga, CA) in the prone position with the superior sagittal sinus horizontal.

To induce acute hydrocephalus, the dog's neck was first flexed to provide better access to the atlantooccipital area. The atlantooccipital dura was surgically exposed and an 18-gauge angiocatheter was carefully inserted at the midline with its tip directed toward the fourth ventricle. After advancing the catheter 2 to 3 mm, the stylet was removed and the catheter was gently advanced approximately 2 cm more through the foramen so that the tip lay in the cephalic half of the fourth ventricle. MR images were used to determine specific distances for each study using known anatomic landmarks. Slow injection of 0.3 to 0.4 mL of Silastic filled the fourth ventricle and extended into the aqueduct. Polymerization time of the Silastic polymer was approximately 5 minutes. The wound was sutured closed and the animals were treated with antibiotics and analgesics.

In five dogs, a burr hole was made approximately 3 mm lateral to either side of midline and 20 mm anterior to the internal auditory canal. Exact coordinates for each animal were determined from earlier MR images. A 20-gauge angiocatheter was introduced into one lateral ventricle, and, using a closed system, CSF pressure was measured for the first 3 hours after the induction of hydrocephalus using a Camino Laboratories (San Diego, CA) model V420 pressure monitor. After CSF pressure was measured, 0.1 mL of 0.5 mol/L gadopentetate dimeglumine was introduced into the lateral ventricular system in three dogs. MR imaging was performed after 30 minutes to determine the patency of the Silastic obstruction.

Postinduction T1-weighted transverse and sagittal MR images (750/25; section thickness, 2.0 mm; intraplaner resolution, 0.5 mm) were acquired for dogs at either 6 hours (n = 4) or 24 hours (n = 3), or at both 24 and 48 hours (n = 5), to quantify changes in ventricular volume. To determine the volume, individual areas of each transverse section covering the lateral ventricular system were first measured using our validated computer algorithms. Each area was multiplied by the section thickness (2 mm), and the intersection spacing was extrapolated from their adjacent sections to yield a total volume. For MR imaging at 24 and 48 hours, the animals were awakened after induction of hydrocephalus and later reanesthetized when needed. The dogs were then sacrificed using approved methods.

Induction of acute hydrocephalus was simple and reliable, and in no case were there postsurgical complications or mortality. The location of the polymerized Silastic within the fourth ventricle and aqueduct was clearly visible as a lack of MR signal on the midline sagittal images (Fig 1). The effectiveness of this obstruction was confirmed by the placement of contrast material in three dogs, as no MR contrast enhancement was observed beyond the obstruction.

The average normal baseline ventricular pressure in five dogs was 14.6 ± 2.8 cm H_2O. The average pressure after 3 hours of acute hydrocephalus was 40.2 ± 5.7 cm H_2O, or a 275% increase.

Figure 2 shows the MR images of a representative dog before and at 24 and 48 hours after induction of hydrocephalus. In the preinduction images, the anatomy of the ventricles, brain tissue, and sulci is normal. In the postinduction images, significant lateral ventricular enlargement is obvious, particularly at 48 hours, and effacement of the sulcal spaces is evident.

In three of the 15 dogs, little ventricular distention occurred, which was attributed to an incomplete obstruction of CSF outflow at the level of the fourth ventricle. For the other 12 dogs, the normal preinduction average ventricular volume was 2.19 ± 1.34 cm^3. After induction, the ventricular volume increased on average 1.45 ± 0.94 cm^3 (146%), 1.92 ± 0.82 cm^3 (213%), and 2.24 ± 0.60 cm^3 (270%) after 6, 24, and 48 hours of hydrocephalus, respectively (Fig 3).

Discussion

In the present study of acute noncommunicating hydrocephalus in a canine model, the introduction of Silastic into the fourth ventricle proceeded simply and without complication. This hydrocephalic model is consistent with acute processes that block the normal pathways of CSF flow through the fourth ventricle or distal aqueduct of Sylvius. Immediate physiological changes in CSF pressure and volume can be readily determined.

Previous experimental studies concerning the induction and evaluation of chronic hydrocephalus have involved either the placement of kaolin (5) or

Silastic (6, 7) in the cisterna magna or basal cisterns. With these methods, hydrocephalus develops slowly, and pressure and volume changes are measured over several days to several weeks. The irritant kaolin, however, produces an inflammatory response, causing cerebral swelling and histologic damage that may alter CSF physiology and histologic interpretation. This makes the introduction of kaolin into the fourth ventricle unsuitable for use in an acute model of hydrocephalus. On the other hand, Silastic is noninflammatory and was ideal for use in the present study. In a similar experiment, Drake et al (4) also used Silastic to induce acute hydrocephalus; however, they studied only three dogs, of which one died in the perioperative period and only two were examined with MR imaging, either at 2 or 7 days after the induction of hydrocephalus.
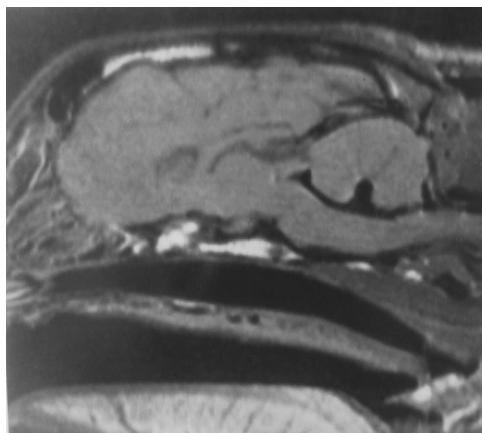

FIG 1. Sagittal MR image of a representative dog shows the distribution of Silastic, seen as minimal MR signal, in the fourth ventricle and aqueduct.
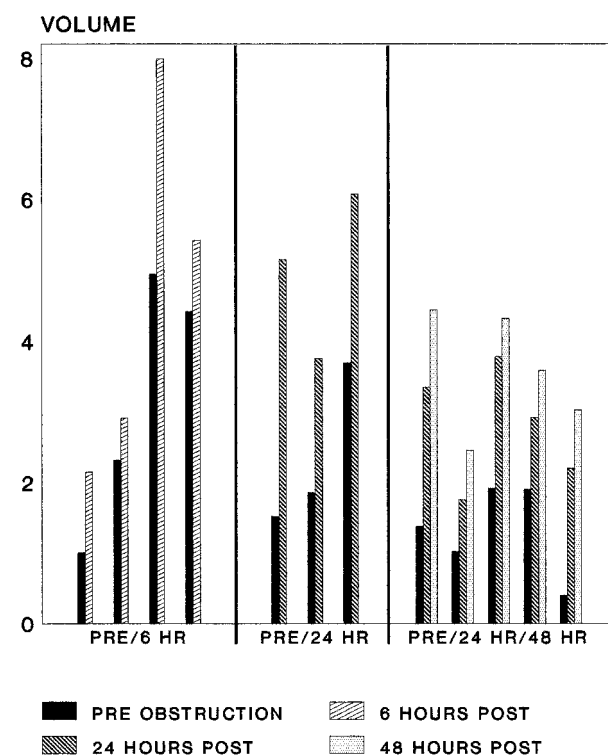

FIG 3. Changes in lateral ventricular volume (cm^3) in 12 dogs with acute hydrocephalus.
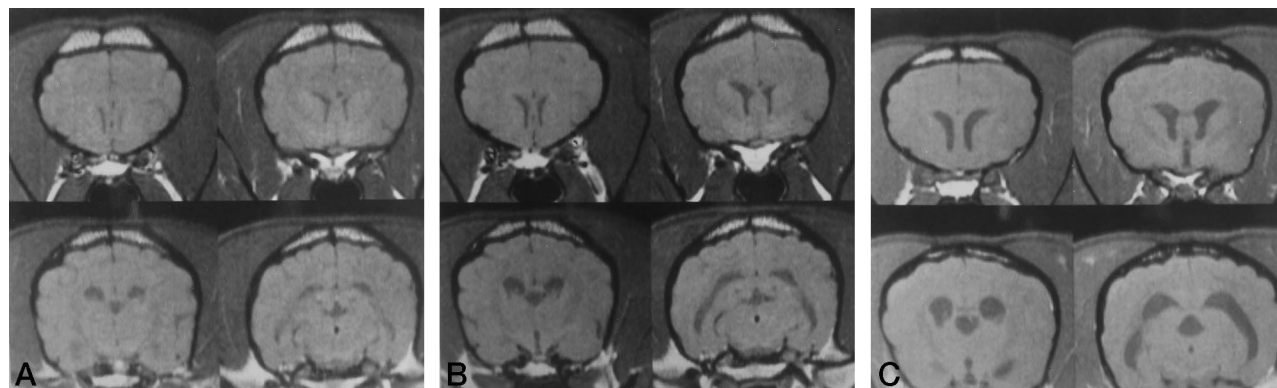

FIG 2. Transverse MR images of a representative dog acquired before (A), 24 hours after (B), and 48 hours after (C) induction of hydrocephalus.

The normal baseline ventricular pressure of the five dogs we studied was 14.6 ± 2.8 cm H_2O, which is consistent with that found in other studies (7). Changes in pressure were immediate and rapid and were indicative of complete obstruction at the level of the fourth ventricle. This was confirmed in three dogs by evaluating the patency of the obstruction using contrast material placed in the lateral ventricles. The distribution of Silastic in the fourth ventricle and aqueduct of Sylvius was clearly seen on midline sagittal MR images. Significant changes in lateral ventricular volume seen as soon as 6 hours after induction of hydrocephalus is also consistent with obstructive hydrocephalus. Although not quantified, a dramatic increase in the size of the third ventricle was noted. In the three dogs in which lateral ventricular distention did not develop, an incomplete obstruction was suspected but not absolutely determined.

A large variability in the preinduction ventricular volumes was observed. Other studies have shown that certain canine species exhibit a broad range of normal cerebral ventricular size (8). In the 15 dogs used here, more than a 10-fold difference was observed in the presurgical ventricular volumes, a difference that is considered to be of normal variance. Consequently, assuming the rate of CSF production is similar, both the ventricular compliance and percentage of expansion caused by experimental hydrocephalus vary significantly from one dog to another. This is reflected in the observed ventricular pressure and volumetric changes.

Conclusion

Placement of Silastic in the fourth ventricle and aqueduct of Sylvius is an appropriate model of acute hydrocephalus. The average lateral ventricular pressure increased 275% within 3 hours and ventricular volume increased 248% within 48 hours. The relatively nonreactive nature of Silastic will not affect CSF physiology or cell morphology, and will thus lend itself to additional studies of histologic alterations that accompany obstructive hydrocephalus.

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