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Sonographic Evaluation of Experimental Hydrocephalus in Kittens

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Real-time computed sonography was used to monitor ventricular size in kittens with experimentally induced hydrocephalus. Hydrocephalus was induced by cisternal kaolin injection in newborn kittens in order to study the effects of both hydrocephalus and subsequent ventriculoperitoneal shunting on the morphology of brain tissue. When severe hydrocephalus was achieved, marked physical and neurologic abnormalities were identified by the investigators. However, when milder degrees of hydrocephalus were achieved, no neurologic abnormalities could be detected and only subtle physical signs such as palpable sutures were seen. In order to know when to shunt the kittens (or when to sacrifice kittens in the nonshunted control group), we needed to quantitate milder degrees of hydrocephalus in vivo. Sonography is the technique of choice in evaluating human infants and children with hydrocephalus and open fontanelles [1, 2]. We found sonography to be an acceptable technique in imaging the kittens with hydrocephalus. Although the fontanelle closes early and remains closed, sonography of the brain is possible in hydrocephalic kittens because of the development of soft spots in the coronal sutures. However, in kittens who have been successfully shunted, the soft spots close quickly and the brain is no longer accessible to sonographic evaluation.

The purpose of this paper is to present our technique and findings regarding the capability of sonography as a research tool in the evaluation of the brain of normal kittens, as well as in kittens who have had hydrocephalus experimentally induced and treated by ventriculoperitoneal shunts.

Materials and Methods

At 4–10 days of age, 73 kittens received kaolin injections into the cisterna magna. The technique for this procedure is described elsewhere [3–6]. Twenty-six kittens were used as controls and received saline injections into the cisterna magna under identical surgical conditions. After the cisternal injections, the kittens were returned to the care of their mothers. Ventriculoperitoneal shunting was performed at 12–18 days after kaolin injection in 12 of the kittens who developed hydrocephalus. Because of the small size of the kittens, flow-dependent neonatal ventricular access devices (Pudenz-Schulte Medical, Santa Barbara, CA) were used [6].

Sonographic examinations were performed using an Acuson 128 real-time scanner with a 5-MHz sector transducer. To ensure adequate acoustic coupling, the fur over the anterior fontanelle and the coronal sutures was shaved just before sonographic study. The kittens were neither sedated nor anesthetized. The scans were performed in the coronal and sagittal planes through the anterior fontanelle or "sutural soft spots." Researchers interpreted the sonograms without knowledge of whether the subject had received a kaolin or saline injection. The ventriculocranial index (VCI) was defined as the ratio of the diameter of the lateral ventricles to the diameter of the inner table of the skull as measured on a coronal image through the third ventricle. This index was used to group shunted and nonshunted kittens so that subjects with similar degrees of hydrocephalus could be compared.

Sonographic studies of the brain of the kittens were performed 1–2 days before cisternal injection, 3–5 days after cisternal injection, and thereafter at intervals of 5–7 days until the animal was sacrificed or died. After the initial group of kittens was evaluated, we stopped doing the sonographic study before injection because it had provided no additional information. Hydrocephalus does not occur naturally in kittens. The kittens who received a ventriculoperitoneal shunt were studied by sonography 1–2 days before ventricular shunt placement, 2–3 days after shunting, and thereafter at intervals of 5–7 days or until the skull was too thick and no longer had an acoustic window.

Sonographic Findings

Normal Kittens

The anterior fontanelle of normal kittens remains open until the age of 4–5 days and is sufficiently large during this time to permit diagnostic sonography. The diameter of the brain

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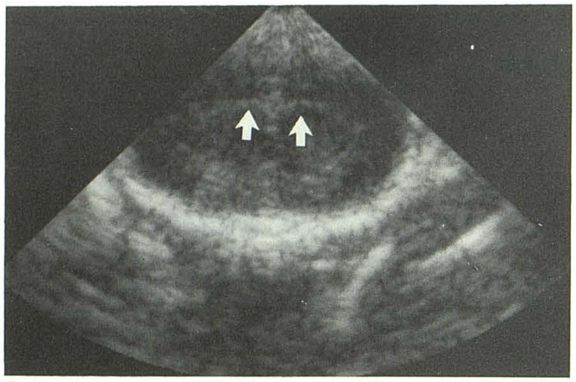

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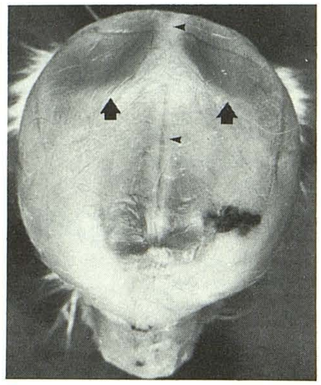

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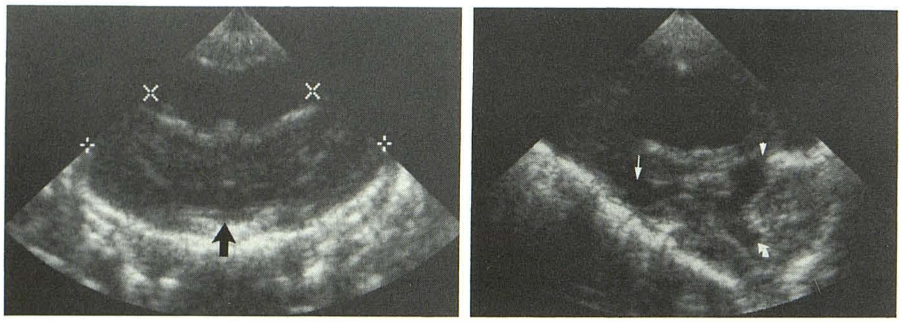
Fig. 1.—Coronal sonogram of normal newborn kitten. Ventricles are slitlike but can be identified by echogenic choroid plexus (*arrows*).

Fig. 2.—Photograph of hydrocephalic kitten skull with sutural soft spots (*arrows*). Note closed sagittal suture (*arrowheads*). Face is at top, and posterior cervical spine is at bottom of photograph.



A B

Fig. 3.—Sonogram of hydrocephalic kitten: *A*, coronal; *B*, midline sagittal. Note dilated third ventricle (*arrows*) and dilated fourth ventricle (*curved arrow*). Superior extent of the fourth ventricle (*arrowhead*) represents recess of inferior colliculus. X cursors mark the ventricular diameter, and the + cursors mark cranial diameter. These measurements are used to calculate ventriculocranial index.

of a newborn kitten is about 2 cm. Therefore, it is necessary to use sonographic equipment that is capable of resolving fine detail in the near field. The ventricular system of the cat is similar to that of humans; however, the cat cerebrum is considerably smaller in size relative to the midbrain. In normal kittens, the lateral ventricles are slitlike and are recognized on sonograms by the presence of the echogenic choroid plexus that lines the floor of the lateral ventricles (Fig. 1). The normal third and fourth ventricles are not seen.

Hydrocephalic Kittens

Of the 73 kittens who received cisternal injections of kaolin, 90% developed hydrocephalus. In all of the kittens with experimentally induced hydrocephalus, the anterior fontanelle and the sutures closed and did not reopen; however, thinning and softening of the bony vault developed on either side of the midline in the region of the coronal suture (Fig. 2). These sutural soft spots developed even when hydrocephalus was mild, and they persisted in all the kittens with hydrocephalus until they died or were sacrificed. The sutural soft spot served as an excellent acoustic window, and hydrocephalus was readily detected by sonography. As in humans, the most striking ventricular dilatation occurred in the lateral ventricles (Fig. 3A). However, because the induced obstruction to the ventricles was below the level of the fourth ventricle, enlargement of both the third and the fourth ventricles was observed (Fig. 3B).

Shunted Kittens

Sonography was useful in monitoring the success or failure of the ventriculoperitoneal shunts. The initial shunt procedure was shown by sonography to be successful in 10 of the kittens and unsuccessful in two of the kittens. A revision of the shunt was carried out in the two failures. In the kittens whose shunts needed revision, the sutural soft spots persisted, allowing for sonographic documentation of continued hydrocephalus. In the kittens with successful shunts, the sutural soft spots closed within 5 days of the shunt procedure, and sonographic evaluation was no longer possible.

Although sutural soft spots did not reappear in one kitten in whom sonography showed successful shunting, mild ventriculomegaly was found when the kitten was sacrificed 16 days after the shunt procedure.

Discussion

Radiographic and radionuclide imaging procedures have been previously described in adult cats and dogs with experimentally induced hydrocephalus. These procedures have been done to study ventricular size [7] and to study flow and absorption of CSF [8, 9]. A disadvantage of these techniques is the injection of material into the ventricles, which may add an additional factor to the inflammatory and biochemical changes identified.

Sonography of the brain in cats and kittens has not been reported previously. In normal kittens, sonography is of little use because the fontanelles close early and there is no access to the brain by the ultrasound beam. In kittens with experimentally induced hydrocephalus, sonographic evaluation is possible because of the soft spots that appear in the region of the coronal sutures. To our knowledge, these soft spots have not been previously described. Sonography provided a noninvasive method of imaging the ventricles in kittens that were to be shunted and not sacrificed. It also helped to determine when kittens should be sacrificed so that the effect of mild or moderate hydrocephalus could be studied.

Thus, sonography of the brain was useful in kittens with experimentally induced hydrocephalus because it showed relative degrees of ventriculomegaly and thus provided an in vivo correlation for the morphologic and biochemical alterations being studied in infantile hydrocephalus.

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