Diagnosis of internal and external hydrocephalus in a warmblood foal using magnetic resonance imaging

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Introduction

Congenital hydrocephalus is an uncommon condition which occurs with abortion, stillbirth or birth of weak and maladjusted equine neonates. Clinically, congenital hydrocephalus without massive malformation of the skull may be indistinguishable from other neonatal neurologic disorders (e.g., hypoxic-ischemic encephalopathy or bacterial meningitis). Though today’s diagnostic imaging modalities give excellent possibilities to examine equine’s brain, only a few MR studies of equine brain disorders have been published so far.

Case report

Patient and history

A 10-day-old female Hannoverian foal (body weight 60 kg) with a slightly abnormal skull shape and maladjustment syndrome was presented at the Clinic for Horses of the University of Veterinary Medicine Hannover. According to the medical report, no complications had occurred during delivery. The foal’s level of consciousness, however, had decreased shortly after birth. The sick foal did not nurse from the mare and did not exhibit a suckle reflex. Due to the inadequate dietary intake, the foal was force fed with mare’s milk and a milk replacement formula by repeated nasogastric tubing.

Clinical and hematologic examination

On the day of hospitalization, the foal’s state of development and nutrition was within the normal limits for its age. On clinical examination, an abnormal cranium with a low-grade turricephalic shape was noted. The foal’s heart rate was 72 bpm, its rectal temperature was 38.4 °C, and it had a respiratory rate of 44 breaths per minute. On auscultation, slightly harsh inspiratory and expiratory lung sounds were heard. Beyond that, all examination results were normal; umbilicus, joints, and eyes showed no clinical indication of sepsis. The sepsis score was 2 (a score of 12 or higher predicts a sepsis, a score of 11 or less predicts non-sepsis) (3).

During the neurological examination, the foal appeared dull and lethargic. Intermittently, strong head flexion, chewing, and an overall lack of orientation to the dam were noticed. The foal’s posture and motion were unimpaired, and the posture and balance reactions were normal for its age. The menace response was absent. The other cranial nerve responses and the spinal reflexes were normal.

The laboratory examination showed a slightly increased percentage of segmented neutrophil granulocytes (73%, reference range: 45–70%) in the blood. The IgG was between 4 and 8 g/L (reference range > 8 g/L). The concentration of sodium and chloride in venous blood was increased (158 mmol/L, reference range: 126–137 mmol/L; 117 mmol/L, reference range: 95–105 mmol/L, respectively) (2).

Further examinations

Radiography

The head was examined radiographically (latero-lateral projection, 63 kV; 20 mAs; 18.4 ms). This enabled the precise documentation of the dome shaped skull (Fig. 1). The latero-lateral thoracic radiographs (117 kV; 10 mAs; 14.6 ms) showed an alveolar pattern in the cranioventral lung regions. The pulmonary tissue was slightly radio-opaque in the cardiophrenic angle.

On the basis of the clinical, neurological and radiographic examinations the tentative diagnosis of hydrocephalus was made. However, a hypoxic-ischemic encephalopathy could not be excluded as differential diagnosis. Secondary to this, the diagnosis of aspiration pneumonia was confirmed.
Magnetic resonance imaging and computed tomography

A magnetic resonance imaging (MRI) study of the head was performed under general anesthesia (Fig. 2–4) using a 1-Tesla scanner (Magnetom impact plus 1.0 Tesla, Siemens, Erlangen, Germany). T1-weighted (T1W) spin echo and T2-weighted (T2W) fast spin echo sequences were performed in sagittal, dorsal and transverse planes. FLAIR images were obtained in the transverse plane. Additionally, T1W transverse images were acquired after intravenous application of a contrast agent (Gadolinium-dDTPA, Magnevist®, Schering Deutschland GmbH, Berlin, 0.2 mmol/kg BW).

The dome-shaped frontal bone was visible in all sequences. The configuration of the cerebellum was nearly physiological; the dorsorostral parts were slightly flattened, but signal intensity and architecture were normal (Fig. 2). The mesencephalic aqueduct appeared prominent whereas the thalamus, the quadrigeminal plate, the brain stem and the spinal cord were without pathological findings in the MRI. The neocortex appeared narrow and ring-shaped in all sequences (Fig. 2–4). Its width was between 10 and 16 mm, and no gyri or sulci could be found. A clear cortical white to gray matter border could not be recognized in any sequence. Between the skull and the neocortex, there was a 10 to 20 mm wide, fluid-isointense ring-shaped signal, isointense to cerebrospinal fluid (CSF) considered to be an enlarged subarachnoid space. A signal of similar fluid-isointensity was obvious between the ring-shaped neocortex and the remaining diencephalic and mesencephalic structures considered to be the enlarged lateral ventricular system (Fig. 2, 3). Dorsolateral to the left part of the quadrigeminal plate, an irregularly shaped hypointense signal was detectable in T2W images (Fig. 4), which appeared soft-tissue-isointense in the T1W sequence. Signal intensities were typical for acute hemorrhage. After application of a contrast agent, a physiological enhancement in the neural parenchyma was visible. Linear signals connected the cortex and the skull (Fig. 3).

**Fig. 1** Laterolateral radiographic imaging (63 kv; 20 mAs; 18.4 ms) of the foal’s skull. Notice the turricephalic shape and the abnormal head flexing.

**Fig. 2** Midsagittal T2W image of the brain. The neocortex (1) is narrow and ring-shaped, without normal structure of visible gyri and sulci, and surrounded by a fluid-isointense signal, representing the severely widened subarachnoid space (2). Severely enlarged fluid-filled ventricle (3).

**Fig. 3** Transverse T1W post contrast image of the brain at the level of the thalamus. The neocortex (1) is narrow and ring-shaped, without normal structure of visible gyri and sulci and surrounded by the severely widened subarachnoid space around neocortex (2). Severely enlarged fluid-filled ventricle (3).

**Fig. 4** Transverse T2W image at the level of the thalamus (slightly caudal to the section shown in Fig. 3). Intracranial hemorrhage (1). Severely widened subarachnoid space filled with cerebrospinal fluid (2).
In addition to the MRI, a computed tomography (CT) of the skull was performed (Fig. 5). Corresponding to the MRI study, the ventricular system and the subarachnoidal space were markedly enlarged. The neocortex was narrow and ring-shaped and the bony structures were normal.

**Analysis of cerebrospinal fluid**

Subsequently, cerebrospinal fluid (CSF) was sampled, firstly by puncture of the atlanto-occipital space and secondly by penetration of the fontanel at the frontal bone. The CSF was slightly turbid and xanthochromic at both puncture sites (turbidity +2 according to Furr and Andrews [7]). There was a slightly increased number of erythrocytes (atlanto-occipital: 107/μl; fontanel: 187/μl) and white blood cells (atlanto-occipital: 37/μl; fontanel: 6/μl) with an increased percentage of segmented neutrophil granulocytes (atlanto-occipital: 25%; fontanel: 90%). No signs of bacterial infection were detected by microscopic examination. The microbiologic examination of the CSF showed no evidence of bacterial growth.

**Tentative diagnosis**

On the basis of the imaging findings, the tentative diagnosis of a severe internal and external hydrocephalus was made. In addition, acute bronchopneumonia was diagnosed based on the clinical examination and radiographic findings. The foal was euthanized due to the poor prognosis.

**Postmortem examination**

At postmortem examination, the filly showed dorsal distention and doming of the skull (Fig. 6a). Within the cranial cavity, there were up to 300 ml of a clear CSF (external hydrocephalus). The cerebrum measured approximately 12 cm width, 10 cm length and 6 cm height, while the cerebellum and the brain stem were normally developed (Fig. 6b). Within the cerebrum, there was a fluid filled cavity consisting of communicating lateral ventricles of about 8 cm width, 7 cm depth and 3 cm height (internal hydrocephalus). At the base of this cavity, a circumscribed hematoma (1 × 1.5 × 0.7 cm) was seen.

Additionally, the filly exhibited a moderate multifocal suppurative to necrotizing pneumonia with abscessation in the cranioventral lobes of the lung, a suppurative aerosacculitis, a mild suppurative rhinitis as well as a suppurative omphalitis with abscessation.

Microscopically, the spinal cord displayed a mild expansion of the central canal in all segments. The hippocampus was hypocellular (Fig. 7). Bulbus olfactorius and cerebrum did not show any evidence of necrosis, atrophy or degeneration. The pons and the mesencephalic aqueductus, brain stem and cerebellum were without significant changes. In the meninges, acute hemorrhage, fibrosis and mineralization were found. The lung displayed a suppu-

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**Fig. 5**
Transverse non-contrast CT image (soft tissue algorithm) at the same level as in Fig. 3. The neocortex (1) is narrow and ring-shaped, surrounded by the severely widened subarachnoid space around neocortex (2). Severely enlarged fluid-filled ventricle (3).

**Fig. 6a** Pathological findings: Dome-shaped skull.

**Fig. 6b** Pathological findings: Diminished cerebrum in an enlarged cranial cavity with a normally developed cerebellum.
In the case described, diagnosis of internal and external hydrocephalus was made by MRI and CT studies of the foal’s head. Other examinations such as CSF analysis on its own are unable to detect this rare congenital disease. An increase in intracranial pressure (ICP) can be a sign of a hydrocephalus, but also appears in other cerebral diseases, such as hematoma formation, abscessation or neoplasm (12). Unfortunately, ICP was not measured in this case. Physiological ICP values were examined in normal neonatal foals by using a subdural catheter (10), but no ICP values of foals with internal and external hydrocephalus have been published yet. Because of massive accumulation of CSF and atrophy of cerebral tissue, an increase in ICP could be suspected in this case.

The CSF obtained from the atlanto-occipital space and from the fontanel region showed significantly increased leukocytes and total protein values as well as an increased amount of erythrocytes at both sites. No inflammatory changes of meninges and brain tissue were detected histologically which could alter CSF. Thus, the results indicate a possible contamination of the CSF with blood during extraction.

In hydrocephalic foals, radiographic examination alone reveals little about the accumulation of fluids in the skull area. The only radiological feature of note in this case was the distension of the skull, which was already noted during the clinical examination. In horses, pneumoencephalography, as described by Bester et al. (1), is a far less accurate method for diagnosis than either MRI or CT examination. It is also an invasive diagnostic tool and thus, with the increasing availability of cross sectional imaging modalities, practically obsolete.

An ultrasonographic examination of the brain through the fontanel (13), which is an easy and inexpensive technique with good results in humans and miniature dogs with open fontanels (8), could not be performed in this case due to the almost complete closure of the bony structures. In cases such as this, it is therefore necessary to carry out the more cost-intensive CT or MRI examination under general anesthesia.

In neonatal foals, MRI of the skull is the most accurate and sensitive imaging modality for diagnosing diseases of the central nervous system. MRI examinations of normal neonatal cadaver foals have been carried out and provide important information and reference values for the structures in the normal foal’s head (4). MRI has been shown to be a useful diagnostic tool for neurological disease in horses, and could therefore also be beneficial in diagnosing congenital abnormalities or inflammatory central nervous disorders of the neonatal foal (e. g. bacterial meningitis, cerebral edema or intraventricular hemorrhage) (4, 5). CT examination was able to demonstrate internal and external hydrocephalus in this case, but MRI studies offer more precise diagnostic information of the brain tissue. Similar to MRI, CT is an expensive examination which requires general anesthesia. Therefore, in human and veterinary medicine, MRI is the preferred modality for diagnostic imaging of brain tissue.

In human medicine in general and especially in neonatal medicine, MRI is used as an important, non-invasive diagnostic imaging technique for CNS-disorders (13) and other soft tissue abnormalities. It is used for diagnosing brain damage as a result of trauma, neoplasms, or infections. MRI is also valuable for the diagnosis of congenital diseases, such as hydrocephalus, brain malformations, and tumors. In newborns, MRI is especially useful for the evaluation of suspected brain abnormalities, which may be difficult to detect with traditional radiographic techniques. MRI can provide detailed images of the brain and spinal cord, allowing for the identification of abnormalities such as lesions, malformations, and tumors. Additionally, MRI can be used to monitor the response of treatments and to evaluate the outcome of surgical procedures.
of perinatal asphyxia syndrome and could be carried out to determine the prognosis (11, 14). Compared to CT, pathological changes of the brain in human hydrocephalus, e. g. interstitial edema or white matter infarcts, can be displayed more effectively. Furthermore, diagnostic findings in several planes are much easier to visualize with MRI.

The therapeutic approach to hydrocephalus in human neuroradiology is a surgical one. Using a ventriculoperitoneal shunt, an artificial liquor outflow into the abdominal cavity is created, but is frequently complicated by wound infections (9). Foreman (6) described an attempt to create an artificial CSF drainage into the thoracic cavity of a foal, which however was not successful. Because of the lack of realistic surgical options and the additional pulmonary disease, therapy was not considered for the presented foal and it was euthanized because of the poor prognosis.

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Conflict of interest
The authors confirm that they do not have any conflict of interest.

References

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