Technical Communication

Rationale and Technique for Examination of Nervous System in Suspected Infant Victims of Abuse

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Abstract: Most victims of fatal child abuse are under the age of 2 years and have a fairly typical pattern of injuries that involve the brain and spinal cord. Documenting these injuries in a systematic fashion is of paramount importance in establishing the cause and manner of death. Although the importance of recognizing these injuries is widely understood, there are few guidelines for the optimal examination of the central nervous system to document these changes. A standard procedure for postmortem dissection of the brain and spinal cord that preserves the anatomy of the cervicomedullary junction is outlined. Changes in the cervicomedullary junction and spinal cord are an underappreciated marker for shaking injury in children. This technique, along with examination of the eyes and optic nerves, will optimally identify the injuries associated with shaking injuries. A standard series of histologic sections are also outlined to document the corresponding microscopic changes.

Key Words: child abuse, brain and spinal cord injuries, dissection techniques, shaken battered baby

(*Am J Forensic Med Pathol* 2004;25: 29–32)

The majority of victims of child abuse are less than 2 years of age, and, in fact, over half are a year or less. Injuries are often inflicted by shaking and/or battering (ie, mechanical trauma), and the resulting pattern of lesions is often relatively predictable. No external injury of the head or back is obvious in many victims, especially if the primary mechanism was shaking rather than battering. Under these circumstances, there are 4 specific injuries that result from violent shaking: (1) subdural hematoma (typically between the 2 cerebral hemispheres); (2) retinal and optic nerve sheath hemorrhages; (3) tears of cerebral white matter (especially corpus callosum); and (4) tears and hemorrhages of cervical (or more caudal) spinal cord and/or nerve roots.

In view of these facts, a standard procedure for postmortem dissection should be followed to document the presence or absence of any or all of these abnormalities. Evidence of any other abnormalities must also be observed and documented as well, some of which might include contusions and/or lacerations, bruising, fractures, patterned injuries, burns, signs of asphyxiation, etc. Because spinal injuries are most commonly located in the high cervical region, it is critical that the brain stem and spinal cord be removed in continuity as damage cannot be identified if the medulla is separated from the cord in the routine way.

A number of authors, primarily referring to the removal of brains from adult cadavers, have outlined useful techniques that maintain the continuity of the brain and spinal cord, preserving the integrity of the cervicomedullary junction.[1–4] Others have suggested specialized techniques for the handling of perinatal brains to minimize tissue disruption.[5,6] We have modified these techniques and drawn upon our own experience over many years in developing the following technique.

Technique

Following careful external examination, the body should be placed prone on the table. A midline incision (using the spinous processes of the vertebrae as a guide) starting at the occipital bone and extending to the natal cleft (cleavage of the buttocks) should be made. Dissection and retraction of the underlying tissue, especially in the cervical region, will reveal hemorrhages or other injuries if present. The soft tissues should then be dissected away from the transverse processes that protect the underlying spinal cord.

Manuscript received March 3, 2003; accepted July 29, 2003.

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ISSN: 0195-7910/04/2501-0029

DOI: 10.1097/01.paf.0000113811.85110.54

Next, the laminae are cut to expose the cord. If the decedent is an infant 2 months of age or less it may be possible to cut the laminae with scissors or a cartilage cutter. Otherwise, the saw must be used but with care, especially in infants. It is important to note that this process must extend through all the posterior laminae, including those of the axis (C2) and the atlas (C1), up to the occipital bone.

Following elevation of the laminae, notation should be made of any blood that might have accumulated in the epidural space. At this stage, considerable care must be exercised in preparing the cord for removal. The dura at the lumbosacral level should be grasped gently with a rat tooth forcep, and a scalpel with a #11 blade should be used to cut the spinal roots at their exit foramina and the anterior ligament. This should be done gently to prevent maceration and adventitious cuts. Care should be taken in this process not to pull too strongly on the dura or to kink the cord. Particular care must be exercised in the cervical region. The spinal dura is often tightly adherent to the connective tissue and bone at the level of the atlas and the foramen magnum. Carefully working around the spinal cord, the #11 blade should be used to completely free the dural sheath at this level. Failure to do this will make it difficult to deliver the spinal cord through the foramen magnum at the end of the dissection. After all roots and ligaments have been cut and the cord with the surrounding dura can be lifted from the vertebral canal, the laminae should be replaced and the soft tissue reapproximated.

The body can now be carefully placed in a supine position with the head elevated. The ear-to-ear scalp incision and reflection of the scalp can now be made and any hemorrhages or other abnormalities documented. The skull should be examined for fractures, abnormal separation of sutures, or other injuries. Dura must be stripped from the inner table of the calvaria to identify fractures. If the victim is a baby 6 weeks or less, it is often possible to enter the intracranial cavity by cutting along suture lines with scissors. If the skull has calcified, a saw must be used but with great care for it is usually thin and the blade can easily enter the underlying brain.

Following removal of the calvaria, the character, volume, and location of subdural blood should be noted. The cerebral hemispheres should be *gently* separated to allow examination of the corpus callosum in situ. This is especially important if the decedent has been maintained on a respirator for hours or days, in which case the brain is generally softer than normal.

To deal with the soft consistency of the brain in babies, as well as respirator cases, it may be helpful to place the body or at least the head in a shallow basin filled with 1 to 2 inches of formalin or water. As the neck is extended and the head tipped back, the water will help support the cerebral tissue during subsequent dissection steps and will help keep the brain intact during removal.

The brain should then be dissected along its basal connections with the cranial nerves, carotid arteries, and infundibular stalk. The tentorium is then cut along the petrous ridge bilaterally. Using a scalpel with #11 blade, cranial nerve roots coming off the brain stem and the vertebral arteries should be cut, along with any connective tissue that binds the structures in the region of the foramen magnum to the dura.

Since the cord has already been freed, it is now possible to remove the brain and cord in continuity from above. If this cannot be done easily, there must not be any pulling or tugging. Instead, the cause of the holdup should be identified and dealt with. The most common problem is failure to free the spinal dura along the ventral surface of the atlas and the foramen magnum. Once free, the brain with attached spinal cord should be weighed and, along with the dura, placed in formalin. The addition of a small amount of 37% formalin, the undiluted stock concentration, will cause the brain to float, preventing artifacts caused by settling of the brain on the bottom of the container.

The skull can now be examined for fractures after the dura has been stripped. Failure to remove the dura from the skull base will result in many missed skull fractures. The orbits should be unroofed and both eyes removed along with at least 1 to 2 cm of attached optic nerve. It is critical that the junction of the optic nerve to globe be included in the specimen.[7] Examination of the petrous bones with exposure of the middle ear may also be performed as clinically indicated.

The presence of blood in the basal cisterns or the cisterna magna in particular indicates the possibility of vertebral artery injury, and consideration should be given to dissecting the soft tissue of the neck, as well as the course of the vertebral artery in its passage through C1 to C6 to document the presence of injury in this vessel.

A modification of this technique that can be helpful in some cases is the creation of a posterior window over the cervicomedullary junction. This can be readily accomplished by various techniques, depending on the age of the child. This requires that the incision over the spine be extended up through the occiput and that the overlying soft tissues be dissected to expose the underlying occipital squamous bone. In infants, an incision into the lambdoid suture can be extended along its length bilaterally to outline the squamous portion of the occipital bone down to the foramen magnum.[4] The bone can then be gently elevated and the dural attachments severed. Alternatively, if there is more advanced calcification of the skull, a Striker saw may be used to cut a wedge of occipital bone extending from the foramen magnum to where you would make the posterior margin of the saw cut to remove the calvaria.[3]

Fixation, Gross and Microscopic Examination

Following weighing and general external examination of the specimens (brain, spinal cord, eyes, blood clots), tissues should be placed in fixative. The period of fixation is variable, but when there is minimal fixation before cutting the brain, the tissue may remain quite soft and will require additional fixation before acceptable routine histologic sections can be produced.

Systematic gross examination should be performed after fixation. Coronal sections of cerebral hemispheres and transverse sections of the brain stem, cerebellum, and cord are then done, lesions being documented and photographed if appropriate. If a blood clot is located at an unusual site, it should be processed for the possibility that it contains a vascular malformation.

Since a considerable number of victims are maintained on a respirator before death is pronounced, the pathologist is at a disadvantage because *intra vitam* autolysis results in softening and tissue disintegration, the extent of which is generally correlated with the duration of respirator therapy. If it is prolonged, ensuing tissue acidosis may interfere with success in obtaining evaluable hematoxylin and eosin–stained (H&E) slides.

Sections for microscopic study should be taken from the following sites, if possible. If sampling is limited, those regions designated with an asterisk are the most crucial. In general, tissue for microscopic study is taken from the left hemisphere unless a specific lesion is seen on the right side.

1. Superior frontal gyrus 2 cm posterior to pole.
*2. Gyrus rectus at same level.
*3. Centrum ovale primarily in anterior half of brain.
*4. Sections of corpus callosum through genu, anterior, midbody and splenium, plus any other levels displaying abnormality (see Fig. 1). Do not cut in midline sagitally unless it is already transected.

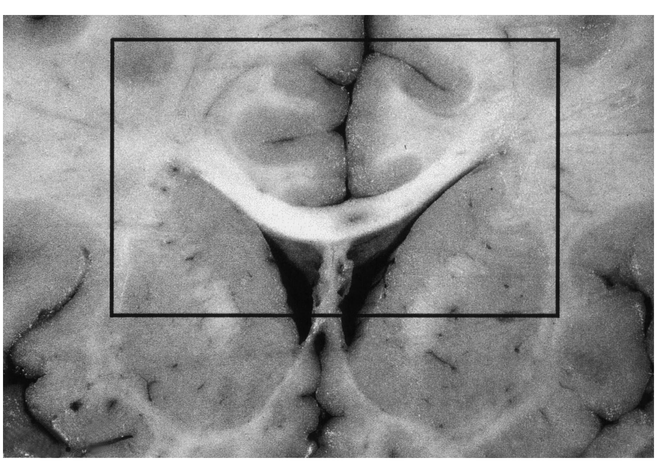

FIGURE 1. Coronal section of the brain at the level of the corpus striatum. Rectangular area indicates an ideal area for histologic sections of the corpus callosum. Note the presence of a small hemorrhage in the corpus callosum, consistent with diffuse axonal injury.

5. Motor cortex at level of genu of the internal capsule.
6. Section of pallidum and anterior thalamus.
7. Section of putamen and insular cortex.
8. Thalamus at level of posterior limb of internal capsule.
9. Parietal cortex at same level.
*10. Hippocampus.
11. Calcarine cortex.
12. Midbrain: transverse section.
13. Sagittal section of cerebellar vermis.
14. Dentate nucleus.
*15. Rostral pons at level of locus ceruleus, including superior cerebellar peduncle, tegmentum, and tectum.
16. Midpons level of middle cerebellar peduncles.
17. Medulla: mid and caudal.
*18. Junction of medulla and spinal cord.
*19. *All* of spinal cord including nerve roots (especially dorsal roots and ganglia) and dura with epidural fat.
*20. Both eyes, including the optic nerves with dural covering. Technician cuts optic globe on either side of optic nerve and embeds it in continuity with nerve but not before a transverse section of nerve has been cut (Fig. 2).
*21. Dura and/or subdural/epidural clots.

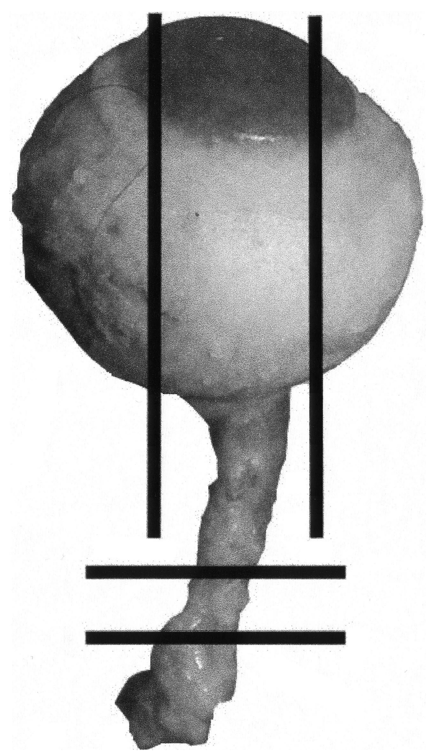

FIGURE 2. Globe with attached optic nerve. Parallel lines through globe and insertion of optic nerve denote the ideal histologic section for identifying pathologic changes associated with traumatic injury. Transverse sections of the nerve, horizontal parallel lines, should also be examined.

Caveats

If a lesion is seen elsewhere, it should obviously be sampled, especially the olfactory bulbs/tracts, foci of subarachnoid hemorrhage with or without contusions, and contusions. The cerebellum is an uncommon site of injury unless there is a fracture of the occipital bone. It is also important to keep in mind that isolated intracerebral hemorrhages with or without a subdural hematoma are rare consequences of child abuse. If such are found, it is important to consider the possibility of a coagulopathy of some kind on a ruptured vascular malformation.

Routine H&E stains are generally adequate for the majority of cases. If more precise evaluation of axons is desirable, the Bodian silver stain, neurofilament protein, and/or the beta amyloid precursor protein immunohistochemical staining are useful in documenting both intact normal structures and evidence of axonal injury.

Microscopic study should focus upon identification of whether any of the following is present:

1. Acute neuronal necrosis (distribution should be documented).
2. Acute swelling, pyknosis and/or karyorrhexis: apoptosis of oligodendroglia (easiest to identify and most commonly found in cerebral or cord white matter).
3. Retraction balls/axonal swelling and/or fragmentation.
4. Frank tissue necrosis with or without hemorrhage or cellular reaction. It should be noted that abundant hemorrhage is not generally a striking feature of parenchymal lesions.
5. Unsuspected inflammatory disease that might account for or have contributed to the death, or a hitherto silent tumor.

CONCLUSION

In summary, a determined effort to document natural and unnatural diseases or abnormalities should be made before drawing conclusions regarding the cause and manner of death. Ultimately, diagnosis of "shaken-battered baby" is based upon a constellation of clinical and pathologic features that, taken together, are not characteristic of any other known disease or accidental injury. This can only be accomplished after complete and systematic evaluation of the central nervous system. The procedures outlined above are based upon our long experience in dealing with these cases, as well as a review of the literature related to techniques for removal of the brain and spinal cord. Maintaining the integrity of the spinal cord, particularly the cervicomedullary junction, will allow for optimum examination of these structures. Based on our experience, careful gross examination and histologic sections will often reveal the presence of injuries in the cord, nerve roots, or hemorrhages in these structures that confirm the presence of traumatic injury related to abuse.

ACKNOWLEDGMENTS

This material was presented, in part, by one of the authors (L.B.R.) at an NIH sponsored conference, Inflicted Childhood Neurotrauma, and appears in the proceedings of this conference, Inflicted Childhood Neurotrauma: proceedings of a conference sponsored by Department of Health and Human Services (HHS), National Institutes of Health (NIH), National Institute of Child Health and Human Development (NICHD), Office of Rare Diseases (ORD), National Center for Medical Rehabilitation Research (NCMRR). Reece RM, Nicholson CE (eds). American Academy of Pediatrics, 2003.

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