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CERVICAL SPINE MRI IN ABUSED INFANTS

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Abstract—Objective: To determine clinical utility of screening with cervical spine MRI to detect unsuspected cord injury in children with head injury from child abuse. Design: Prospectively collected case series. Setting—Tertiary care children's hospital and county medical examiner's office. Patients: Twelve children with intracranial injury secondary to child abuse. None was clinically suspected to have cord injury. Includes all eligible children whose attending felt: (a) needed follow-up cranial imaging; (b) could be safely imaged; and (c) whose caretakers consented between November, 1991 and September, 1994. Interventions: MRI scans of the cervical spine were obtained either more than 3 days after clinical presentation or postmortem. Main Outcome Measures: Clinical observations by neurologist, child protection team pediatrician and medical examiners by prospective protocol. MRI scans evaluated by prospective radiology protocol with emphasis on cervical cord injury. Results: Four of the five autopsied children had small subdural or subarachnoid hemorrhages at the level of the cervical spine; MRI scan did not identify them. MRI did not identify cord injury in any child studied. Conclusion: Routine cervical spine MRI scans are probably not warranted in children with head injury secondary to child abuse without clinical symptoms of cervical cord injury.

Key Words—Child abuse, Abusive head injury, Cervical spinal cord trauma, Cervical spine MRI scan.

INTRODUCTION

ISOLATED CASES OF paralysis secondary to cervical spinal cord injury in abused/head injured infants have been reported (Gosnold & Sivaloganathan, 1980; Grabb & Pang, 1994;

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Piatt & Steinberg, 1995; Sneed & Stover, 1988; Swischuck, 1969; Towbin, 1967) and we have observed a similar case at the Children's Hospital and Medical Center (CHMC). Since these children usually present with brain trauma, it may be very difficult for clinicians to recognize and appropriately manage coexistent cord trauma (Sneed & Stover, 1988). That such injuries might be more frequent than clinically apparent is suggested by both mechanism and autopsy study. The postulated mechanism of injury in abusive head injury, whiplash shaking with or without associated impact trauma, could put great stress on the cervical spine and cervical cord. Hadley found subdural or epidural hematomas of the cervical spine accompanying proximal spinal cord contusions in five of six autopsied, whiplash shaken infants (Hadley, Sonntag, Rekate, & Murphy, 1989). Ommaya also found similar cord injury in biomechanical studies of whiplash injury in monkeys (Ommaya, Faas, & Yarnell, 1968).

Although spinal cord injury is frequently irreversible, early corticosteroid treatment has been reported to reduce sequelae (Kriss & Kriss, 1996). Prompt diagnosis is imperative to initiate corticosteroid therapy and to stabilize the spine to prevent further injury.

Reports of vertebral bone and ligament injuries in abused children have been more frequent than of cord injury, but, of these, cervical injuries are rarest (Swischuck, 1969). Further, children who suffer cervical cord injuries frequently lack associated skeletal abnormality, a condition reported in the literature as "spinal cord injury without radiologic abnormality" (SCIWORA) (Grabb & Pang, 1994; Kriss & Kriss, 1996; Swischuck, 1969). The relatively large head in childhood, spinal hypermobility, and spinal ligament laxity have been postulated to result in temporary bony column displacement without fracture. Cord injury may then result from longitudinal distraction, hyper-flexion or extension, or subsequent ischemic changes (Grabb & Pang, 1994; Kriss & Kriss, 1996). Clinical findings may be masked by coexistent central nervous system symptoms and readily available radiologic studies may underestimate the degree of neural injury.

Although myelography can document impingement on and swelling of the cord, it is an invasive test that risks morbidity in children with increased intracranial pressure. A noninvasive imaging method is needed to aid diagnosis of cord injury.

The magnetic resonance imaging (MRI) scan was first used in the 1970s. It has proved a sensitive technique to study the brain and spinal cord. It has also proved to be a safe imaging method. However, the generally long imaging times requiring patient immobility and sedation make it unlikely to be the modality of choice for acute, unstable, childhood head injury. The compute tomograpy (CT) scan is more effective for rapidly imaging acute, surgically significant bleeding and skull fractures. The MRI scan, however, appears to be an effective method, complementing the CT scan in followup of abusive head injury after the child becomes clinically stable. In that setting the MRI scan has been sensitive to parenchymal injury, including evidence for subacute or remote bleeding (Alexander, Schor, & Smith, 1986).

There have been individual case reports (Chen & Blaw, 1986; Kriss & Kriss, 1996; Piatt & Steinberg, 1995; Saleh & Raycroft, 1992) and one case series (Grabb & Pang, 1994) of the MRI scan's use to evaluate childhood cord trauma. The MRI scan also has been successfully used to image adults with suspected cervical cord trauma (Kaifas, Willberger, Goldberg, & Prostko, 1988). Thus, MRI appeared to us an appealing modality for further prospective study. Hadley's report of bleeding around and injury to the cervical cord in autopsied children who had been abused (Hadley, Sonntag, Rekate, & Murphy, 1989) also led us to question whether the MRI scan might, by identifying cord injury in living shaking/impact victims, provide additional forensic evidence of their mode of injury.

We prospectively studied the cervical cord of abused/head injury infants with the MRI scan in an attempt to delineate the frequency of identifiable cord abnormalities. Studies were performed when the children were clinically stable and the child's attending physician felt that

scanning would not impose clinical risk (eight patients) or when the children were dead (four patients). MRI findings were correlated with clinical examination, and in cases of fatality, pathologic study.

MATERIALS AND METHODS

The study was conducted at the CHMC in Seattle, Washington and the King County Medical Examiner's Office (KCME). CHMC is a tertiary care children's hospital serving the Pacific Northwest. Through its legal mandate to investigate all unexplained and/or injury related deaths in the county, the KCME receives all King County infant deaths related to trauma for autopsy.

The study was conducted with CHMC Human Subjects Review Committee approval. By hospital policy, children suspected to have head injury secondary to child abuse are referred to the child protection team. Parents and physicians of these patients were approached for study enrollment. Except for one dead on arrival victim, all children had initial cranial imaging performed by CT scan. Final study enrollment required a positive diagnosis of inflicted head injury and clinical stability (as judged by the infant's attending physician) sufficient to allow safe transport to the scanner and sedation for the study. If needed, sedation was provided with chloral hydrate. The attending physician must also have judged a follow-up cranial scan to be clinically indicated. Caretaker consent to scan the cervical spine as an experimental study in addition to the indicated cranial MRI study was required. The study was described to the child's parents as a study of the efficacy of the MRI scan to evaluate for cervical cord injury in head injured infants, not *abusively* head injured infants.

Since this study was a preliminary exploration to see whether the scan would be sensitive to subclinical injury, scans were to be conducted three or more days post-injury. By this time, we expected the MRI scan to be more likely to identify blood products than immediately following injury, and parenchymal injuries to be more apparent. In addition, although diagnosis at that time would not allow early corticosteroid treatment or spinal stabilization, earlier scanning would have been technically more difficult and more risky to the child.

Scans were conducted on a General Electric 1.5 Tesla MRI Scanner (Milwaukee, WI). Cervical studies included both T_1–and T_2–weighted imaging. Costs of cranial MRI scans were billed through usual channels, but the cervical portion of the scans was funded by a grant from the General Electric Corporation.

Clinical evaluations by the hospital's pediatric child abuse consultant and pediatric neurology were conducted. When autopsied, the medical examiners conducted cervical cord evaluation by study protocol. All cervical cords were dissected free, two by posterior and three by anterior approach. Observation for spinal cord and cervical spine abnormality was made *in situ* by the medical examiners; formalin fixed brains and spinal cords were examined by neuropathologists from the University of Washington. Microscopic sections of the spinal cords were reviewed in four of five cases; they were not taken in one case lacking gross cord abnormality.

RESULTS

From November, 1991 through September, 1994, 12 children were studied. Included were 10 children hospitalized at CHMC. During the same time period, 23 infants with inflicted head injury were evaluated at CHMC. The remaining 13 infants were not studied because of either: (a) lack of caretaker consent; (b) clinical recovery precluding need for further scanning; (c) attending physician concerns about clinical stability for transport and time required for MRI

scanning early in the child's course; or (d) attending physician concerns about the need for sedation after the children became more active. Five children died and were autopsied. Included were one infant dying prior to and four after hospitalization. Four MRI scans were conducted postmortem, three within 1 day and one at 2 1/2 days after death. All of these children had died within 48 hours of clinical presentation. The eight scans conducted during life were obtained between 3 and 24 days (median 6 1/2) after clinical presentation. One child scanned while alive subsequently died and was autopsied. Mean age of the victims was 5.8 months, median 2.8 with a range of 1.3 to 34.1 months. Five (42%) of the victims were male.

Children's Coma Scales (normal range 0–14) (Milstein & Morray, 1987) ranged from 0 to 14, mean 7, for the 11 children who were alive at the time of clinical presentation. Seven of these infants lacked physical or neurologic findings suggestive of cervical cord injury. The four children who had peripheral flaccidity and areflexia also had very poor Children's Coma Scales of 0–1, making recognition of coexistent cord injury more difficult.

None of the MRI scans of the 12 evaluated infants showed evidence of cervical cord injury or bleeding around the cord. Diffuse, thin subdural hemorrhage (SDH) overlying the upper cervical cord was identified at autopsy in one of the five infants who died. This was in continuity with similar diffuse cranial SDH. Three infants had subarachnoid bleeding (SAH) over the cervical cord at autopsy; in all of these cases this SAH was associated with either cranial or thin, extensively distributed spinal SAH. Two of these children also had CT scans performed and had CT evidence of cranial SAH. No gross or microscopic changes were noted in the spinal cords of autopsied children, except for one cord with hypoxic neuronal changes.

All children had cervical spine radiographs as part of a skeletal survey for trauma; all were normal. None of the infants had CT examination of the cervical spine.

The 12 negative MRI studies resulted in 95% confidence that further scans would result in positive results in 22% or less of patients similar to those studied (Hanley & Lippman-Hand, 1983).

All studied infants had evidence of central nervous system injury (Table 1). Evidence of impact trauma to the head (cranial vault contusions, skull fractures, cortical contusions) was

Table 1. Injuries Observed in Children with Inflicted Head Injury

Injury	*N* with Injury/*N* Evaluated[a]
Scalp/Calvarium Surface Bruise	8/12
Swollen Scalp	3/12
Bruise Under Scalp Surface	3/5
Other Bruises	7/12
Intraoral Trauma	2/12
Genital or Rectal Trauma	2/12
Skull Fracture	2/12
Brain Contusion	3/12
SDH, Old	4/12
SDH, Acute	11/12
SAH	9/12
Retinal Bleeding	10/12
Acute Rib Fractures	2/12
Old Rib Fractures	3/12
Acute Long Bone Fractures	5/12
Old Long Bone Fractures	2/12
Anemia (Hct $\leq$ 30%)	8/11
(Mean for Anemic Children 25%, range 18–30%)	

[a] *N* evaluated is the number of children who underwent testing capable of detecting the abnormal finding. For example, bruises under the scalp could only be evaluated in the five autopsied infants.

present in nine (75%) of the victims. Evidence suggestive of shaking events (acute posterior rib fractures or acute epiphyseal/metaphyseal chip fractures) was present in six (50%) of the infants. Four (33%) had evidence suggestive both of shaking and impact injury. One caretaker eventually provided history of shaking alone, two caretakers of impact events alone, and two caretakers of both shaking and impact. Ten (83%) of the infants had retinal bleeding. Associated injuries are listed in Table 1.

Discussion, Context, and Implications

Our study confirms Hadley's observations that small extra-axial hemorrhages frequently overlie the cervical cord in infants dying as a result of inflicted head injury (Hadley, Sonntag, Rekate, & Murphy, 1989). They were seen both with and without evidence of cranial impact injury. Whether they resulted from impact events or resulted from associated shaking remains unknown. These small collections were, however, not apparent using pre- or postmortem cervical MRI scanning in our study.

In the subjects studied it was also not productive to search with the MRI scan for cervical cord injury in infants without physical or neurologic examinations suggestive of spinal cord injury. As opposed to Hadley (Hadley, Sonntag, Rekate, & Murphy, 1989), we did not find injury to the cord itself at autopsy. Because of the difficulty obtaining consent for study from parents and attending physicians, we were only able to study slightly less than half of the victims of head injury from abuse. Although complete study recruitment would have been ideal, the children studied seemed to be representative of the full spectrum of neurologic injury from apparent clinical recovery to death. Since none of the autopsied infants had cervical cord abnormality and survivors lacked cord symptoms, our study does not provide further evidence about the MRI scan's ability to image cord injury. However, reported results of the acute MRI study of adults with symptoms of cervical cord injury document its efficacy (Kaifas, Wilberger, Goldberg, & Prostko, 1988). Grabb's institutional series of children with SCIWORA which includes one abused child (Grabb & Pang, 1994) and the case report of Piatt (Piatt & Steinberg, 1995) suggest that the MRI scan may also be a valuable diagnostic tool in children with inflicted injury who have signs or symptoms of cord dysfunction. The MRI also has been shown to be an effective means of imaging extraneural spinal injuries in SCIWORA; in particular, injuries of spinal ligaments and discs (Grabb & Pang, 1994). Because MRI may not image bony injuries as well, plain radiographs and/or cervical CT scans may still be required to evaluate structural abnormalities of the spine.

Our series, which included both infants with evidence of shaking and of impact, found SDH over the cord in only one of five autopsied infants. Hadley's series (Hadley, Sonntag, Rekate, & Murphy, 1989), which attempted to evaluate a pure series of shaken infants without evidence of impact, found either EDH or SDH over the cord or cord contusion in five of six autopsied infants. In spite of the frequency of these anatomic findings, he did not report and we did not observe clinical cord dysfunction. Given the violent flexion and extension of the neck during shaking events, it seems surprising that more clinical cord injury wasn't observed. However, cord injury should be more likely with translational subluxations between individual vertebrae or very abrupt, short segment angular spine distortions. Since shaken children seem to most often be held by the chest or arms, this may allow the rotational forces to be evenly distributed along the entire length of the cervical spine.

Since only isolated case reports are available, the frequency of clinically significant cord injury in infants with inflicted head injury is undocumented. Cervical cord injury occurs in about 2% of adult victims of serious head injury (O'Malley & Ross, 1988). If similar frequencies apply to infants, focused vigilant evaluation will be required to recognize these

devastating injuries. In the presence of coexistent head injury, clinical findings of cord dysfunction will continue to be subtle and masked. Given our current lack of specific information about the frequency of subtle infant cord injury and the potential hazards of corticosteroids in brain injured patients, it would be premature to recommend empiric treatment with cord-protective doses of corticosteroids in abused infants without clinical evidence of cord dysfunction.

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Résumé—Objectif: Evaluer l'intérêt clinique d'un dépistage par RMN dans le but de diagnostiquer des atteintes de la moelle épinière ignorées chez des enfants présentant des lésions de la tête, dues à un abus. Méthode: Une série de cas collectés prospectivement. Environnement: Un hôpital d'enfants de 3ème niveau et un cabinet d'examen médical du conté. Patients: 12 enfants présentant des lésions intracrâniennes dues à un abus. Aucun ne présentait de signes cliniques d'atteinte de la moelle épinière. Ont été inclus, tous les enfants potentiellement éligibles entre novembre 91 et septembre 94 pour lesquels la personne responsable considérait (a) qu'une image de suivi intra-cérébral était nécessaire, (b) que le patient pouvait être imagé en toute sécurité et (c) que les personnes prenant soin de l'enfant avaient donné leur consentement. Intervention: Des coupes par RMN de la moelle cervicale ont été obtenues plus de 3 jours après la présentation clinique du symptôme ou après le décès. Principales mesures de contrôle: Les observations cliniques par un neurologue, un pédiatre de l'équipe de protection de l'enfance et des examinateurs médicaux au cours d'un protocole prospectif. Les coupes de RMN ont été évaluées par des protocoles radiologiques projectifs avec un intérêt particulier pour les lésions de la moelle épinière. Résultats: Quatre des cinq enfants autopsiés présentaient des petites hémorragies sous-durales ou sous-arachnoidiennes au niveau de la moelle cervicale. Les coupes RMN ne les ont pas identifiées. La RMN n'a identifié aucune lésion de la moelle épinière chez aucun des enfants étudiés. Conclusion: Les coupes RMN de la moelle cervicale effectuées en routine ne sont probablement pas justifiées chez des enfants présentant des lésions crâniennes secondaires à un abus en l'absence de symptômes cliniques sugggérant une lésion de la moelle cervicale.

Resumen—Objetivo: Determinar la utilidad clínica de la realización de una exploracion por imagen por resonancia magnética (IRM) de la columna vertebral cervical para detectar lesiones no sospechadas de la médula en niños con lesión cerebral provocada por maltrato infantil. Diseño: Series de casos recogidos de manera prospectiva. Ambito: Hospital Infantil de atención terciaria y el despacho de Inspeccion médica del Condado. Pacientes: Doce niños con lesión intracraneal secundaria a maltrato infantil. Se incluyeron a todos los niños elegibles que reunian las siguientes condiciones: (a) con necesidad de un seguimiento por IRM; (b) con quienes se podia realizar la IRM con seguridad; y (c) cuyos cuidadores dieron su consentimiento entre Noviembre de 1991 y Setiembre de 1994. Intervenciones: Los exámenes por IRM de la columna vertebral cervical se realizaron después de más de tres días de la presentación clínica o postmortem. Principales medidas de resultados: Se realizaron observaciones clínicas por parte de neurólogos y se completaron unos protocolos prospectivos por parte de inspectores médicos y de pediatras de los equipos de protección infantil. Los exámenes de IRM fueron evaluados a través de un protocolo prospectivo de radiología con énfasis en la lesión de la médula cervical. Resultados: Cuatro de los cinco niños a quienes se hizo la autopsia tuvieron pequeñas hemorragias subdurales o subaracnoides a nivel de la columna vertebral cervical; el examen de IRM no las identificó. La IRM no identificó la lesión de la médula cervical en ningún niño estudiado. Conclusión: El examen rutinario por IRM de la columna vertebral cervical probablemente no está justificado en niños con lesión cerebral secundaria al maltrato infantil sin síntomas clínicos de lesión de la médula cervical.