Neurol Med Chir (*Tokyo*) *46, 57～61, 2006*

Shaken Baby Syndrome: An Odyssey

Ronald H. USCINSKI

Department of Neurosurgery, George Washington University Medical Center, Washington, D.C., U.S.A.; Department of Neurosurgery, Georgetown University Medical Center, Washington, D.C., U.S.A.; Potomac Institute for Policy Studies, Arlington, Virginia, U.S.A.

Abstract

Shaken baby syndrome is evaluated in the context of its historical evolution and its veracity in referring to causal injury mechanisms. A rational assessment of the injury causation and consequent pathological states associated with the syndrome is presented. It is now evident that shaken baby syndrome evolved as a result of a faulty application of scientific reasoning and a lack of appreciation of mechanisms of injury. A brief explanation of the commonly understood usage and interface of scientific methodology and reasoning as applied to clinical medicine is given.

Key words: shaken baby syndrome, injury biomechanics, subdural hematoma

Introduction

Shaken baby syndrome is characterized as a constellation of clinical findings including subdural bleeding, retinal hemorrhages, and associated fractures of the extremities or ribs, with no external evidence of cranial trauma. This widely proclaimed yet still hypothetical supposition has become a virtually unquestioned assumption nowadays as a modality for causing inflicted intracranial injury in infants. In 1997 the author was asked to review the case of a child fatally injured supposedly by shaking, and in doing so researched the entire body of literature referencing the so-called ''shaken baby syndrome.'' This article is a product of that effort, and in a sense represents an intellectual ''odyssey.''[15] The paper is divided into three parts. The first places the syndrome in the historical perspective of the original papers providing the initial description of shaken baby syndrome. The second part gives a brief discussion of the physical laws of motion governing injury to relevant body structures, and encompasses a brief overview of the known pathophysiology of certain relevant forms of intracranial injury. The final section discusses the methodology of scientific reasoning and experimentation and its significance in the context of the immediate subject of the so-called inflicted shaking injury and the broader context of observing and understanding phenomena in our physical world.

Historical Perspective

The quantity of articles dealing with shaking as a putative mechanism for inflicting intracranial injury in infants has increased significantly since the 1970s when the original description of shaking first appeared in a paper published in *The British Medical Journal* in 1971 by Guthkelch.[8] Caffey,[2,3] who is generally credited with identifying and characterizing injuries to infants by shaking, published extensively on the subject thereafter. However, it is in the

---

This excellent paper was presented on May 25, 2005 at the 33rd Annual Meeting of The Japanese Society for Pediatric Neurosurgery in Nara, chaired by Professor Toshisuke Sakaki. All of the audience was greatly impressed by this new and unique concept of the so-called Shaken Baby Syndrome.

Shaken Baby Syndrome has now become a social issue in Japan and neurosurgeons are very much involved in its management. The topic was quite timely, so we thank Dr. Sakaki for selecting this paper as a special lecture for us.

Dr. Ronald H. Uscinski and I were residents together in neurosurgery at the Georgetown University Hospitals, Washington, D.C. in the early 1970s. I am very proud that such an excellent paper was produced in Washington, D.C. and presented in Nara.

Akira YAMAURA, M.D. (Advisory Board of *Neurologia medico-chirurgica*)
President, Chiba College of Health Sciences, Chiba

Guthkelch article that shaking is invoked specifically as a mechanism for causing intracranial injury in infants with no external evidence of cranial trauma. Guthkelch hypothesized that ''It seems clear that the relatively large head and puny neck muscles of the infant must render it particularly vulnerable to whiplash injury in this sort of situation,'' and moreover that ''the rotation-acceleration strains on the brain would tend to occur fairly symmetrically also, in an anteroposterior direction. This may be the same reason why the infantile subdural haematoma is even more often bilateral...''

It is significant that as a mechanical justification for invoking shaking as a mechanism for causing intracranial injury in infants, the original and subsequent authors all reference a single paper by Ommaya et al., published in 1968.[16] In this paper, Ommaya, a neurosurgeon studying head injury and building on earlier work by Holbourn,[9,10] attempted to quantify experimentally the rotational acceleration necessary to cause intracranial injury via a whiplash in rhesus monkeys. The animals in Ommaya's experiment were placed in a contoured fiberglass chair with the head free to rotate; the chair was mounted on wheels and placed on tracks; and the apparatus was systematically impacted with a piston to simulate accelerations analogous to rear-end motor vehicle collisions, with the entire event photographed using a high-speed camera. Ommaya found intracranial injury in 18 of the animals, with concomitant neck injury in 11 of the 18. The purely isolated concept of rotational acceleration of sufficient magnitude to cause intracranial injury without impact and therefore without external evidence of injury was seized upon qualitatively by Guthkelch,[8] Caffey,[2,3] and others as the explanation for hitherto unexplained intracranial injury in infants. This concept was hypothesized and put forth by them as being the result of manual shaking.

Hence, the Ommaya paper emerges as the sole source of experimental data from which the initial hypothetical shaking mechanism was drawn. Significantly, Ommaya was actually attempting to quantify the requisite rotational acceleration necessary to cause head injury via whiplash movement of the head in humans during rear end motor vehicle collisions, with attendant vehicular impact. *He never addressed the question as to whether human beings can shake infants with enough force to produce the acceleration necessary to cause intracranial injury*. It is also significant that neither Guthkelch,[8] Caffey,[2,3] nor any subsequent investigators who have sought to identify and characterize ostensible shaking injuries to the infant head ever asked whether the infant torso and neck anatomy, quite different physiologically from that of the rhesus monkey and of the ''non-infant'' human, could withstand such shaking. Nonetheless, the mechanism of shaking and the so named syndrome gained immediate acceptance and enormously widespread popularity, with no real investigation or even question as to its scientific validity.

The stage was set; the shaking hypothesis rapidly engendered numerous articles purporting to accept or validate the hypothesis. Ratification within the medical community was based principally on anecdotal reports and case studies. The nearly simultaneous establishment in the United States of the Mandated Reporting Laws[4] plus the emerging litigious atmosphere encompassing clinical medicine in America in effect rendered the medical reporting of all cases of even remotely suspected child abuse absolutely compulsory.

The combination of these factors, plus an unspoken, unproved, but increasingly pervasive assumption that all unexplained injuries in children were to be regarded as inflicted injuries, provided a new paradigm for a self-fulfilling prophecy. The hypothesis rapidly metamorphosed to a syndrome; its acceptance expanded exponentially, and ''shaken baby'' became a term synonymous and ultimately identical with intentional child abuse.

Injury Biomechanics

The causes of trauma obey the laws of injury biomechanics. These laws come from the generalized laws that govern motion, deformation, and forces existing in our universe. An example of one of these universal laws is Newton's second law of motion. Newton's second law governs the relationship between mass, acceleration, and force. In other words, given a mass such as a head, the acceleration of such a mass is governed by Newton's second law when there is a change in velocity divided by a change in time.

In 1943 the physicist Holbourn published a laboratory investigation of traumatic brain injury.[9] Holbourn understood that the deformable brain was incompressible, hypothesized a rotational acceleration level beyond which injury would occur, and that a smaller mass of brain would require larger rotational acceleration. Ommaya himself alluded to this point in his paper,[16] although this seems not to have been recognized by Guthkelch,[8] Caffey,[2,3] and others. In 1987 Duhaime et al.,[7] using available data on scaled injury thresholds, demonstrated that shaking a mechanical model to cause intracranial injury in the form of concussion, subdural hematoma, and diffuse axonal injury, failed to reach such

thresholds. The model used three different examples of the infant neck in order to reproduce mobility. None of these examples addressed the potential for structural failure of the neck. Following the same line of thought from 1987, two of the same authors repeated the experiment,[17] again using a model not addressing neck injury mechanisms, again focusing on rotational accelerations as the mechanism for causing intracranial injury as transmitted through the infant neck, and again demonstrating requisite accelerations to be not achievable by manual shaking.

While the above articles addressed experimentally the impossibility of causing intracranial injury in infants by manual shaking, no work addressed the potential consequence of such shaking activity on the infant neck, the critical link between the torso where the physical act of shaking is initiated, and the infant head where the injury is hypothesized to occur. Bandak precisely addressed this question in a quantitative manner in 2005.[1] In focusing attention on the infant neck, and demonstrating thereby that any transmission of forces generated by shaking the infant torso must necessarily be transmitted through the underdeveloped infant neck to the disproportionately large head, Bandak showed clearly that cervical spinal cord or brainstem injury in the infant would occur at significantly lower levels of shaking accelerations than those purported in the shaken baby syndrome literature as a cause of subdural hematomas. It is now clear that if an infant is subjected to shaken baby syndrome accelerations one should expect to see injury in the infant neck before it is seen in the head. Moreover, such injury should include injury to the cervical spinal cord and brainstem, obviously with the expected accompanying clinical picture.

Based on the above cited material, it is clear that the hypothetical mechanism of manually shaking infants in such a way as to cause intracranial injury is based on a misinterpretation of an experiment done for a different purpose, and contrary to the laws of injury biomechanics as they apply specifically to the infant anatomy. Finally, manual shaking of an infant, if injurious, should result in an entirely different injury biomechanically, physiologically, and clinically, than hypothesized in 1971.

The ''Unexplained Head Injury''

With regard to the cardinal aspect of inflicted injury by the hypothetical shaking mechanism, the ''unexplained head injury,'' the following salient points are worthy of consideration. First, the so-called trivial head impact occurring after a fall of an apparently short distance is believed in most instances to be an innocuous event. In fact this is not so. The free fall velocity from as little as 3 feet results in the equivalent of greater than 9 miles per hour against a hard surface, or more than twice the skull fracture energy for an infant, again as demonstrated by Bandak.[1] Cadaver testing demonstrated skull fractures in infant specimens in every case when dropped from a height of 3 feet (84 cm), or the height of a changing table, onto a firm or hard surface. Fractures in the thin parietal bone were reliably produced when specimens were dropped even onto a softly cushioned surface.[18–20]

Therefore, while the majority of such falls may be seen superficially as innocuous, there exists demonstrably proven potential for serious injury. This is compounded given the potential physiologic response to such injury including vomiting, aspiration, seizing, or other airway compromise with attendant potential for hypoxia, all further complicating the clinical picture. One concludes that rather than resorting to simple generalization, each case warrants careful and individual evaluation.

The second point is that subdural hematoma has hitherto been regarded as a cardinal sign in infants of inflicted injury. While acute subdural hematoma is typically seen after an obvious fall with impact, it must be differentiated from chronic subdural hematoma. Most neurosurgeons treating adult or pediatric patients are aware that chronic subdural hematoma certainly started acutely, but by definition its presence was either not recognized or its significance was not appreciated at the time of injury. This need not imply an intentional injury, and it is a matter worthy of some reflection that intentional injury is rarely diagnosed or even considered in an adult presenting with a chronic subdural hematoma. Yet the same injury with the same pathophysiology and the same pathologic anatomy is nowadays presumed to be intentional in the infant. The scientific grounding for this presumption remains unclear.

Some additional observations are noteworthy here. First, it has long been known among clinical neurosurgeons operating on patients with chronic subdural hematomas that at surgery fresh blood may be found in addition to the older blood comprising the hematoma. Second, it has also been demonstrated experimentally that chronic subdural hematomas enlarge by rebleeding from the neovascular membrane[11–13,21] and that this bleeding has been shown to occur without accompanying trauma. Therefore, at clinical presentation a chronic subdural hematoma may exhibit fresh blood and this may be

mistakenly diagnosed as evidence of recent injury. Lastly, it is known that intracranial hemorrhage may occur even after an apparently uneventful vaginal birth,[5] and it is also well known that a chronic subdural hematoma with well-developed outer and inner membranes is at least several weeks, or even months, old.

The above observations lead one to conclude that for an infant presenting with ostensibly unexplained intracranial bleeding with or without external evidence of injury under given circumstances, accidental injury from a seemingly innocuous fall, perhaps even a remote one, or even an occult birth injury, must be considered before assuming intentional injury.

A recent paper by Donohoe[6] attempted to evaluate the available medical scientific evidence published from 1966 to 1998 wherein internationally accepted methods were used to determine the degree of confidence that accrues to claims regarding the condition termed ''shaken baby syndrome.'' He concluded that some 32 years of cumulative material yielded inadequate scientific evidence to establish a firm conclusion on most aspects of causation, diagnosis, treatment, or any other matters pertaining to shaken baby syndrome. Donohoe's assessment focused on the methods and quality of the actual research. The scientific status of the syndrome itself was not addressed; rather it was the methodology supporting its validity that was found to be insufficient. Another paper by Leestma[14] searched all of the peer reviewed English language medical case literature and analyzed 324 cases that contained detailed individual case information. This search yielded 54 cases in which ''some fashion of admission was noted that the injured baby had been shaken'' (author's words). The details for all 54 cases were analyzed and of those, 11 cases were found wherein the reviewed material yielded no evidence of impact, and 12 cases had evidence of impact. The remaining cases provided either insufficient information or were excluded from the series for other reasons. After attempted statistical analysis of the material, no conclusions could be drawn by the author regarding which injuries occurred because of inflicted or accidental physical forces or by underlying or secondary disease processes, chiefly due to a paucity of data and inconsistent recording of relevant clinical information. That is, it was impossible to determine with scientific rigor what role shaking may have played in abusive head injury in these reported cases. Finally, it was not possible from the case analyses to infer that any particular form of intracranial or intraocular pathology was causally related to shaking, and that most of the pathologies in allegedly shaken babies were due to impact injuries to the head and body.

Science and Shaking

The practice of clinical medicine is considered to be an artistic and a scientific endeavor. In its highest form this is accomplished through the elicitation of a careful and accurate history, and the performance of a thorough physical examination. It is in this manner that an appropriate diagnosis or differential diagnosis is made. In doing so, the physician must understand the principles underlying the normal and pathologic characteristics of the individual patient before him, and how to identify accurately, delineate, and ultimately integrate these characteristics in a way that elucidates the condition of his patient clearly and concisely. The understanding of such principles, however intricate and a priori compassionate, must be grounded in objectivity, logic, and rationality, and must be in conformity with known biologic and physical laws.

There is a balance between the qualitative aspect of caring for people who are sick, and the quantitative, ultimately cognitive understanding of science underlying the practice of clinical medicine. Although this latter understanding may be considered an applied science, it is grounded in principles of science nonetheless. Thus, within the framework of our approach to medicine, the same principles of scientific methodology and understanding are relevant as they are to understanding the nature of the world around us.

Advances in such scientific understanding may occur in two different ways. The first is by objective observation of phenomena occurring in nature, and correlation of this observation with what is already known of the physical universe to produce a more complete understanding and a higher order of comprehension. The second method is by experimentation under controlled conditions where investigators test hypotheses formulated in a methodical, logical, and rational way, in order to explain observed phenomena. This is how our understanding of the world advances, and this is also precisely how medicine advances. Verification of observation leads to verification by experimentation. This is sound scientific methodology. When this methodology produces descriptions and explanations that are in conformity, one has glimpsed a truth. When such descriptions and explanations are at variance, something is amiss, and truth is not identified.

References

1) Bandak FA: Shaken baby syndrome: a biomechanics analysis of injury mechanisms. *Forensic Sci Int* 151: 71–79, 2005
2) Caffey J: On the theory and practice of shaking infants. Its potential residual effects of permanent brain damage and mental retardation. *Am J Dis Child* 124: 161–169, 1972
3) Caffey J: The whiplash shaken infant syndrome: Manual shaking by the extremities with whiplash-induced intracranial and intraocular bleeding, linked with residual permanent brain damage and mental retardation. *Pediatrics* 54: 396–403, 1974
4) The Child Abuse Prevention and Treatment Act (CAPTA) of 1974, Public Law No 93-247 (January 31, 1974)
5) Cunningham F, Hauth J, Leveno K, Gilstrap L III, Bloom S, Wenstrom K: *Williams Obstetrics, ed 22*. New York, McGraw-Hill Medical Publishing Division, 2005, section V: p 682
6) Donohoe M: Evidence-based medicine and shaken baby syndrome: part I: literature review, 1966–1998. *Am J Forensic Med Pathol* 24(3): 239–242, 2003
7) Duhaime A, Gennarelli T, Thibault L, Bruce D, Margulies S, Wiser R: The shaken baby syndrome. A clinical, pathological, and biomechanical study. *J Neurosurg* 66: 409–415, 1987
8) Guthkelch AN: Infantile subdural haematoma and its relationship to whiplash injuries. *Br Med J* 2(759): 430–431, 1971
9) Holbourn AH: Mechanics of head injuries. *Lancet* 9: 438–441, 1943
10) Holbourn AH: The mechanics of trauma with special reference to herniation of cerebral tissue. *J Neurosurg* 1: 191–200, 1944
11) Ito H, Komai T, Yamamoto S: Fibrinolytic enzyme in the lining walls of chronic subdural hematoma. *J Neurosurg* 48: 197–200, 1978
12) Ito H, Yamamoto S, Komai T, Mizukoshi H: Role of local hyperfibrinolysis in the etiology of chronic subdural hematoma. *J Neurosurg* 45: 26–31, 1976
13) Kawakami K, Chikama M, Tamiya T, Shimamura Y: Coagulation and fibrinolysis in chronic subdural hematoma. *Neurosurgery* 25: 25–29, 1989
14) Leestma JE: Case analysis of brain-injured admittedly shaken infants: 54 cases, 1969–2001. *Am J Forensic Med Pathol* 26(3): 199–212, 2005
15) Merriam-Webster Online Dictionary. Springfield, Mass, Merriam-Webster, Inc, ©2005. Odyssey (noun). Available from: http://www.m-w.com/dictionary.htm
16) Ommaya AK, Faas F, Yarnell P: Whiplash injury and brain damage. *JAMA* 204: 75–79, 1968
17) Prange M, Coats B, Duhaime A, Margulies S: Anthropomorphic simulations of falls, shakes, and inflicted impacts in infants. *J Neurosurg* 99: 143–150, 2003
18) Weber W: [Experimental studies of skull fractures in infants]. *Z Rechtsmed* 92: 87–94, 1984 (Ger, with Eng abstract)
19) Weber W: [Biomechanical fragility of the infant skull]. *Z Rechtsmed* 94: 93–101, 1985 (Ger, with Eng abstract)
20) Weber W: [Predilection sites of infantile skull fractures following blunt force]. *Z Rechtsmed* 98: 81–93, 1987 (Ger, with Eng abstract)
21) Yamashima T, Yamamoto S, Friede R: The role of endothelial gap junctions in the enlargement of chronic subdural hematomas. *J Neurosurg* 59: 298–303, 1983

Address reprint requests to: R. H. Uscinski, M.D., Potomac Institute for Policy Studies, Ballston Metro Center Office Tower, 901 Stuart St. ♯200, Arlington, VA 22203, U.S.A.
e-mail: ruscinski@potomacinstitute.org