Internal Jugular Vein Compression Mitigates Traumatic Axonal Injury in a Rat Model by Reducing the Intracranial Slosh Effect

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BACKGROUND: Traumatic brain injury (TBI) remains a devastating condition for which extracranial protection traditionally has been in the form of helmets, which largely fail to protect against intracranial injury.
OBJECTIVE: To determine whether the pathological outcome after traumatic brain injury can be improved via slosh mitigation by internal jugular vein (IJV) compression.
METHODS: Two groups of 10 adult male Sprague-Dawley rats were subjected to impact-acceleration traumatic brain injury. One group underwent IJV compression via application of a collar before injury; the second group did not. Intracranial pressure and intraocular pressure were measured before and after IJV compression to assess collar performance. All rats were killed after a 7-day recovery period, and brainstem white matter tracts underwent fluorescent immunohistochemical processing and labeling of β-amyloid precursor protein, a marker of axonal injury. Digital imaging and statistical analyses were used to determine whether IJV compression resulted in a diminished number of injured axons.
RESULTS: Compression of the IJV resulted in an immediate 30% increase in intraocular and intracranial pressures. Most notably, IJV compression resulted in $>$ 80% reduction in the number of amyloid precursor protein–positive axons as indicated by immunohistochemical analysis.
CONCLUSION: Using a standard acceleration-deceleration laboratory model of mild traumatic brain injury, we have shown successful prevention of axonal injury after IJV compression as indicated by immunohistochemical staining of amyloid precursor protein. We argue that IJV compression reduces slosh-mediated brain injury by increasing intracranial blood volume, which can be indirectly measured by intracranial and intraocular pressures.

KEY WORDS: Amyloid precursor protein (APP), Concussion, Intracranial compliance, Slosh, Traumatic brain injury

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Traumatic brain injury (TBI) continues to be one of the most common causes of death and morbidity in persons $<$ 45 years of age, even in Western societies. A reported 1.7 million people suffer from TBI annually in the United States alone, resulting in an estimated per-annum total cost of over $60 billion.[1] Historically, prevention of skull and brain injury has focused on the use of helmets as external cranial protection. We believe this approach is fundamentally flawed because, regardless of the benefits that helmets have provided for major penetrating brain injuries and skull fractures, both military personnel and athletes are subjected to high-velocity acceleration-deceleration mechanisms that lead to concussive injury.[2] In large part, the relative freedom of movement of the human brain within the cranial cavity predisposes it to both linear and rotational force vectors with resultant axonal tearing.[3] We believe that helmets fail to address the linear and rotational forces imparted on the brain after impact and therefore are inadequate for the prevention of traumatic axonal injury and concussion.

ABBREVIATIONS: APP, amyloid precursor protein; **ICP,** intracranial pressure; **IJV,** internal jugular vein; **IOP,** intraocular pressure; **TBI,** traumatic brain injury

The skull and spinal canal contains only nervous tissue, connective tissue, and fat cells and their interstitium, blood, and cerebrospinal fluid. These fluid contents do not completely fill the rigid container delimited by the skull and bony spinal canal, leaving a "reserve volume." The change in volume inside a container for a given change in pressure is called compliance. Increases in volume of the contents of the skull and bony spinal canal, within the range of reserve volume, occur at low container pressures (owing to the high compliance of the system). In the presence of reserve volume, as seen in a normal physiological state, acceleration to the skull can result in a differential acceleration between the skull and its contents. As a consequence, the brain and fluids collide with the inside of the skull.[3] Considering the semisolid properties of the mammalian brain, we refer to this effect as slosh.

Although helmets are effective in preventing the infrequent penetration or fracture of the skull, they have little ability to limit slosh effects. We believe that mitigating slosh by filling the reserve volume (exhausting compliance) will significantly reduce the propensity for differential motion between the skull and its contents. We reasoned that by mitigating slosh, an accelerating force to the skull would tend to move the skull and its contents in unison, preventing collisions among the intracranial contents and therefore avoiding brain kinetic and vibrational energy absorption.

In an attempt to mitigate intracranial slosh, it is important to recognize that the single intracranial compartment that is most amenable to rapid, reversible change in volume and pressure is the blood. The simplest and most rapid means of increasing the blood compartment is to inhibit its outflow by mechanically obstructing the draining veins in the neck. Thus, the aim of this study was to test the hypothesis that reducing intracranial and spinal canal compliance would mitigate brain injury caused by acute skull acceleration or deceleration (impact). Using a standardized laboratory TBI model, anesthesia was induced to study the effects of internal jugular vein (IJV) compression on brain injury.[4-8]

MATERIALS AND METHODS

Animals

In this work, 2 groups of 10 (total of 20) male Sprague-Dawley rats weighing between 350 and 400 g were used. Animals were acquired from the Hilltop Animal Laboratory (Scottdale, Pennsylvania) and housed under 12-hour light/dark conditions with rat chow and water available ad libitum. All procedures involving live animals were approved by the Institutional Animal Care and Use Committee of West Virginia University and were performed according to the principles of the *Guide for the Care and Use of Laboratory Animals* published by the Institute of Laboratory Resources, National Research Council (National Institutes of Health publication 85-23-2985).

Marmarou Impact-Acceleration Injury Model[4] in Rats

Anesthesia was induced and maintained with isoflurane by a modified medical anesthesia machine. Body temperature was controlled during the approximately 10-minute procedures with a homeothermic heating blanket with rectal probe, and adequate sedation was confirmed by evaluation of response to heel tendon pinch. The animals were shaved and prepared in sterile fashion for surgery, followed by subcutaneous injection of 1% lidocaine local anesthetic into the planned incision site. A 3-cm midline incision in the scalp was made, and the periosteal membranes were separated, exposing bregma and lambda. A metal disk 10 mm in diameter and 3 mm thick was attached to the skull with cyanoacrylate and centered between bregma and lambda. The animal was placed prone on a foam bed with the metal disk directly under a Plexiglas tube. A 450-g brass weight was dropped a single time through the tube from a height of 2 m, striking the disk. The animal was then ventilated on 100% oxygen while the skull was inspected, the disk removed, and the incision repaired. When the animal recovered spontaneous respirations, anesthesia was discontinued, and the animal was returned to its cage for postoperative observation.[4] Buprenorphine was used for postoperative analgesia.

Experimental Protocol

This work involved a control injury group and an experimental injury group, each consisting of 10 animals for a total of 20 animals. In the experimental injury group, the rats were fitted with a 15-mm-wide collar with 2 compressive beads designed to overlay the IJVs that was tightened sufficiently to provide mild compression of the veins without compromising the airway. The collar was then fixed in circumference with a Velcro fastener. The collar was left in position for 3 minutes before administration of the experimental brain injury.

Assessment of Intracranial Reserve Volume

Intracranial Pressure Measurement

Intracranial pressure (ICP) was measured in 5 animals with the FOP-MIV pressure sensor (FISO Technologies, Quebec, Canada) as described by Chavko et al. [9] The head of the rat was shaved and prepped in sterile fashion for surgery. The rat was fixed in a stereotaxic apparatus (model 962; Dual Ultra Precise Small Animal Stereotaxic Instrument, Kopf Instruments, Germany), and a 3-cm midline incision in the scalp was made. Periosteal membranes were separated, exposing both bregma and lambda. A 2-mm burr hole was drilled 0.9 mm caudal from bregma and 1.5 mm from the midline. The fiberoptic probe was then inserted to a depth of 3 mm into the cerebral parenchyma.

Intraocular Pressure Measurement

Intraocular pressure (IOP) was measured in all animals with the TonoLab rebound tonometer (Colonial Medical Supply, Franconia, New Hampshire) as described in the literature.[9-11] The IOP measurements were taken after the induction of anesthesia in all animals and a second time in the experimental group after application of the novel IJV compression device. After application of the IJV compression device in the experimental injury group, IOP readings were taken every 30 seconds while the compression device was in place.

Tissue Preparation and Immunohistochemical Labeling

At 7 days after injury, all animals (n = 20) were anesthetized and immediately perfused transcardially with 200 mL cold 0.9% saline to wash out all blood. This was followed by 4% paraformaldehyde infusion in Millonigs buffer for 40 minutes. The entire brain, brainstem, and rostral spinal cord were removed and immediately placed in 4% paraformaldehyde for 24 hours. After 24 hours of fixation, the brain was blocked by cutting the brainstem above the pons, cutting the cerebellar peduncles, and then making sagittal cuts lateral to the

pyramids. The resulting tissue, containing the corticospinal tracts and the medial lemnisci, areas shown previously to yield traumatically injured axons, was then cut sagittally on a Vibratome into 50-μm-thick sections. The tissue underwent temperature-controlled microwave antigen retrieval with previously described techniques.[12] The tissue was preincubated in a solution containing 10% normal serum and 0.2% Triton X in phosphate-buffered saline for 40 minutes.

For amyloid precursor protein (APP) labeling, the tissue was incubated in polyclonal antibody raised in rabbit against β-APP (No. 51-2700; Zymed, Inc, San Francisco, California) at a dilution of 1:200 in 1% NGS in phosphate-buffered saline overnight. After incubation in primary antibody, the tissue was washed 3 times in 1% NGS in phosphate-buffered saline and then incubated in a secondary anti-rabbit IgG antibody conjugated with Alexa 488 fluorophore (A11008, Molecular Probes, Eugene, Oregon) diluted at 1:200 for 2 hours. The tissue underwent a final wash in 0.1 mol/L phosphate buffer and then was mounted using an antifade agent and placed on coverslips. The slides were sealed with acrylic and stored in the dark in a laboratory refrigerator.[13,14]

Fluorescent Microscopy and Image Analysis

The tissue was examined and images were acquired with an Olympus AX70 fluorescence microscope system (Olympus, Tokyo, Japan). Ten digital images were obtained from the tissue of each animal, and images were then randomized. Individual injured axons were independently counted, and data were stored in a spreadsheet (Microsoft Corp, Redmond, Washington). Differences between group means were determined with paired *t* tests and considered significant at $P < .05$.

Stereological Quantification of Axonal Injury

A stereological method was used to determine an unbiased estimate of the number of APP-positive axons per 1 mm^3 in the corticospinal tract and medial lemniscus. The optical fractionator technique using a Stereo-Investigator 9.0 (MBF Bioscience, Inc, Williston, Vermont) and an Olympus AX70 microscope with 4 × and 40 × objectives was performed. Sagittal APP-stained specimens were examined with low magnification, and regions of interest were drawn incorporating the corticospinal tract and medial lemniscus. The software then selected random 50-μm counting frames with a depth of 15 μm, and APP-positive axons were marked. The volume of the region of interest was determined with the Cavalieri method; the volume of the sum of the counting frames was calculated; the sum total of injured axons within the counting frames was calculated; and an estimate of the number of APP-positive axons per 1 mm^3 was determined.

RESULTS

Assessment of Intracranial Reserve Volume

ICP Measurement

The ICP was assessed both before and after application of the IJV compression device. The baseline ICP was 10.23 ± 1.68 mm Hg and was increased to 16.63 ± 2.00 mm Hg after IJV compression ($P < .01$; Figure 1). Notably, this increase of > 30% from baseline occurred within seconds after IJV compression.

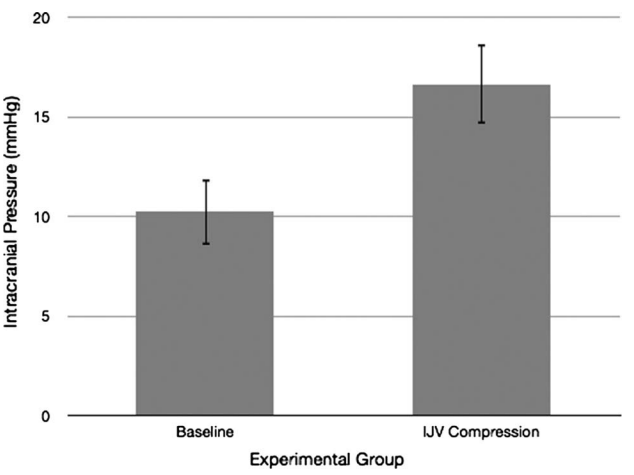

FIGURE 1. *Change in intracranial pressure as a consequence of internal jugular vein (IJV) compression (*P *< .01).*

IOP Measurement

The IOP measurements were taken both before and after application of the IJV compression device, similar to the ICP recordings. The baseline IOP was 11.18 ± 2.27 mm Hg and was elevated to 16.27 ± 3.20 mm Hg after IJV compression ($P < .01$; Figure 2). The increase of 31% seen in IOP after IJV compression is strikingly similar to that seen in ICP after IJV compression in both magnitude and rapidity of response (Figure 3).

TBI Impact-Acceleration Model

None of the animals died of the head trauma. The animals tolerated collar application without any observed untoward effects

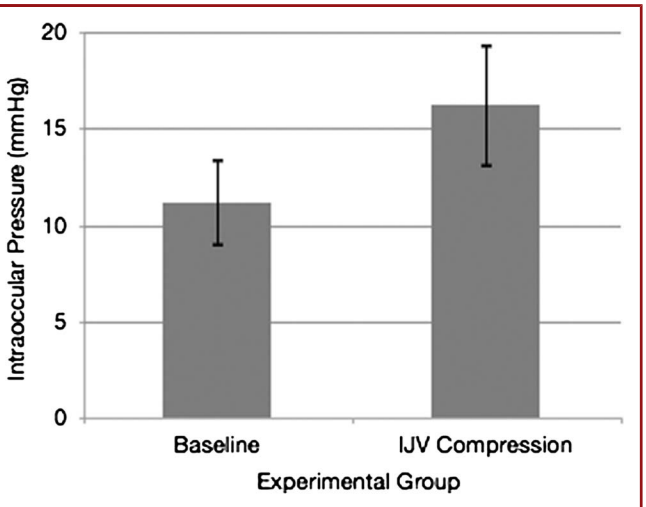

FIGURE 2. *Change in intraocular pressure as a consequence of internal jugular vein (IJV) compression (*P *< .01).*

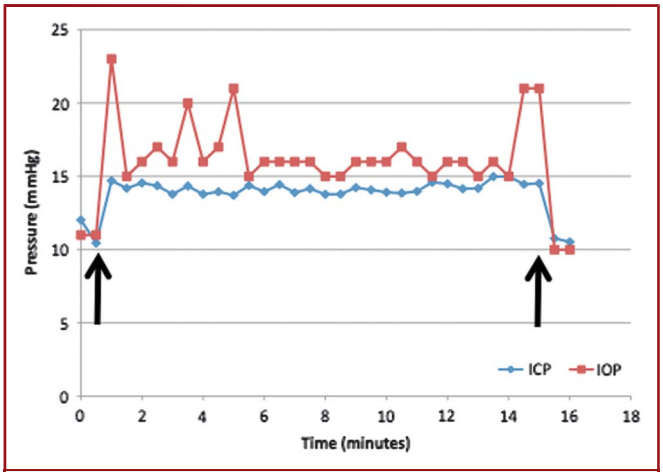

FIGURE 3. *Representative tracing of physiological changes seen in intracranial pressure (ICP) and intraocular pressure (IOP) over a 15-minute period caused by application (arrow on left) and removal (arrow on right) of internal jugular vein (IJV) compression. Of note is the rapid response seen in both ICP and IOP after IJV compression and the duration for which these changes are sustained.*

for the duration of the experiment. Specifically, there were no outward or visible signs of discomfort, intolerance, or respiratory difficulty. All recovered without complication and exhibited normal behavioral and feeding habits up until the day of death. At necropsy, the brains were grossly normal in appearance.

Stereological Analysis of APP-Positive Axons

To determine the density of injured axons in the corticospinal tracts and medial lemnisci, the stereological optical fractionator method was used. Compared with the normal anatomy found in previous experiments with sham animals, control animals without the collar demonstrated focal labeling of APP within many swollen contiguous and terminal axon segments, consistent with impaired axoplasmic transport in traumatic axonal injury. After microscopic digital image acquisition from multiple areas within the corticospinal tract and medial lemnisci from multiple tissue slices, counting of APP-positive axons in animals that received the IJV compression collar demonstrated much fewer APP-positive axons, at a frequency much more similar to sham animals, compared with those undergoing injury without IJV compression (Figure 4). These abnormal axons demonstrated typical morphological characteristics of traumatic injury, primarily swelling and disconnection. By qualitative analysis, the experimental group showed (mean ± SD) 13 540 ± 9808 vs 77 474 ± 25 325 ($P < .01$) APP-positive axons per 1 mm^3 in the control group (Figure 5).

DISCUSSION

Internal vs External Brain Protection

The main finding of this study is that compression of the IJVs for 3 minutes before head trauma led to physiological alterations in intracranial compliance, as evidenced by modest increases in ICP and IOP, while simultaneously and markedly reducing the pathological index of primary neuronal injury in a standardized rat model of TBI. We had reasoned that the reduction in brain volume compliance would prevent the differential motions between the cranium and the brain that lead to energy absorption and neuronal primary and secondary injuries. These pathological changes include axonal tearing that disrupts axoplasmic transport, resulting in axonal swelling and activation of the apoptotic cascades, as evidenced in this model by a statistically significant reduction in APP counts of injured axons.

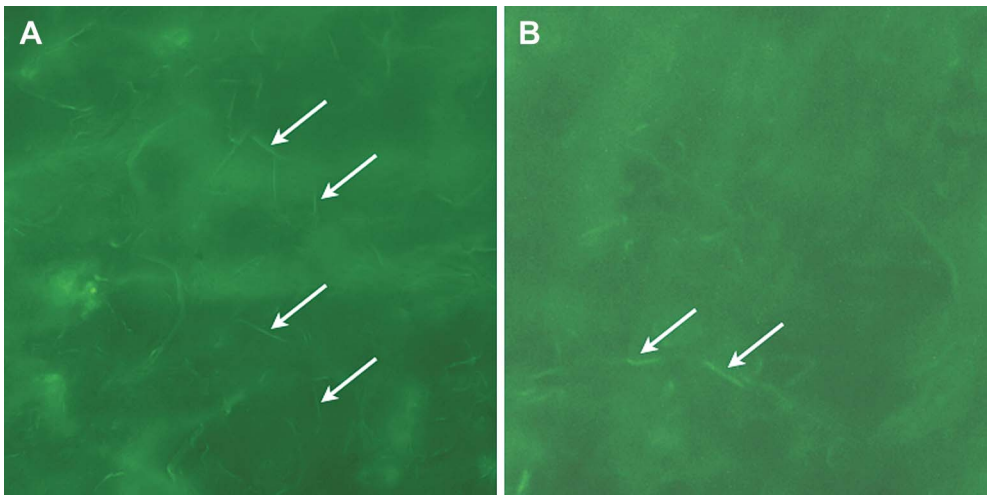

FIGURE 4. *Corticospinal tracts stained for amyloid precursor protein after experimental injury in control animals (A) and in experimental animals with application of internal jugular vein compression device (B). (A) and after control application of the internal jugular vein compression device (B).*

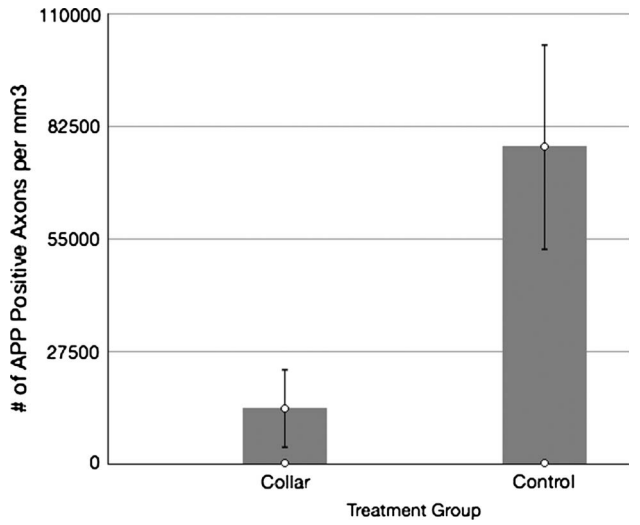

FIGURE 5. *Effect of internal jugular vein compression on axonal injury as indicated by amyloid precursor protein (APP) staining (*$P < .01$*).*

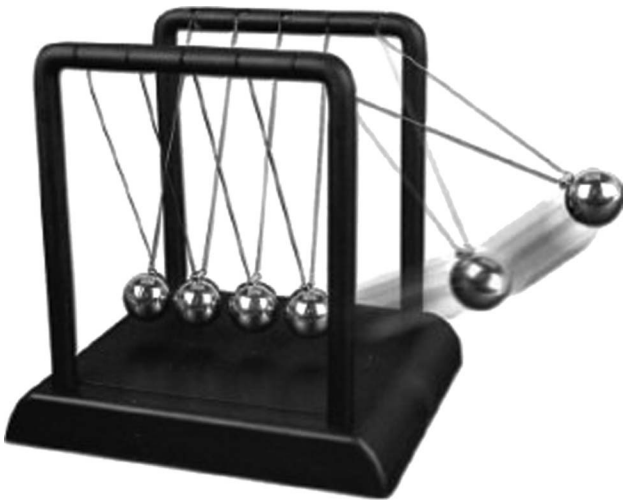

FIGURE 6. *Newton's cradle.*

To date, no effective pharmacological treatment has been discovered for TBI. Although omega-3 fatty acids such as docosahexaenoic acid and progesterone[5] show some promise in animal studies, efficacy in humans has not been proven, emphasizing the importance of prevention in TBI.[6-8] Heretofore, standard prophylactic measures designed to protect the brain against injury in the case of head trauma have emphasized external cranial prevention through the use of helmets. As effective as they may be in preventing penetrating injuries and fractures, helmets have limitations in their protective abilities, especially for concussion and axonal injury.[2] The explanation may be furthered by an analogy to automobiles: Placing additional armor on the outside of the car may not be as effective in preventing passenger injuries during collisions as simply wearing a seat belt or filling up the passenger compartment with an activated airbag. To counteract this reality, our approach involves increasing resistance to venous return and increasing intracranial blood volume, theoretically preventing or reducing the brain movement inside the skull resulting from impact. The energy imparted to a nonsloshing brain space traverses its contents as a series of elastic collisions between molecules rather than being absorbed in the form of frictional, acoustic, and kinetic energies associated with relative motion (shear and collision) between compartments. A well-known example of elastic collisions is Newton's cradle (Figure 6) in which the energy imparted by striking of the first ball-bearing in a series of contiguous suspended ball-bearings is transmitted through the series of contiguous ball-bearings to the last, without apparent motion of those in between.

In our animal model, applying the collar increased intracranial volume, as indicated by an increase in ICP and IOP by 30% and 31%, respectively. In humans, safe, gentle compression of IJVs dates back to 1918 when Quenkenstedt developed a simple test to prove patency of the spinal column. In this maneuver, a spinal needle is placed in the lumbar subdural space and then the IJVs are compressed, causing a rise in spinal pressure. Compression of the IJV may also occur on placement of tight-fitting neck stabilization collars and has been shown to increase ICP,[15] whereas wearing shirts with tight collars or neckties has also been shown to increase IOP.[16] Notably, only mild compressive pressure is required to partially occlude the IJVs because they are a low-pressure system. Because the inflow of cerebral arterial blood continues after partial cerebral venous outlet obstruction, the intracerebral and venous pressures will increase until the jugular venous resistance is overcome or the blood drainage is redirected to other venous channels. In either case, there is a reduction in intracranial compliance and a modest increase in ICP.

Implications to Humans

Increasing intracranial blood volume to provide brain protection from head trauma and blast injuries, in sports or on the battlefield, could be readily implemented by wearing an elastic collar-type device (Figure 7). Mild compression of the IJVs, particularly if applied along some length of the vein, would not pose any danger of airway or carotid compression. Clothing and jewelry, some of which are restrictive in nature and may apply some compression of the neck, are worn ubiquitously without any known adverse effects.

Do Analogous Mechanisms Exist in Nature to Limit Brain Trauma?

In terms of biology-inspired discovery, another species exposed to repeated head trauma is the woodpecker. This bird experiences forces of 1500*g* per peck, for 12 000 pecks a day, totaling about 85 million head impacts over its average lifespan.[17] Its protective

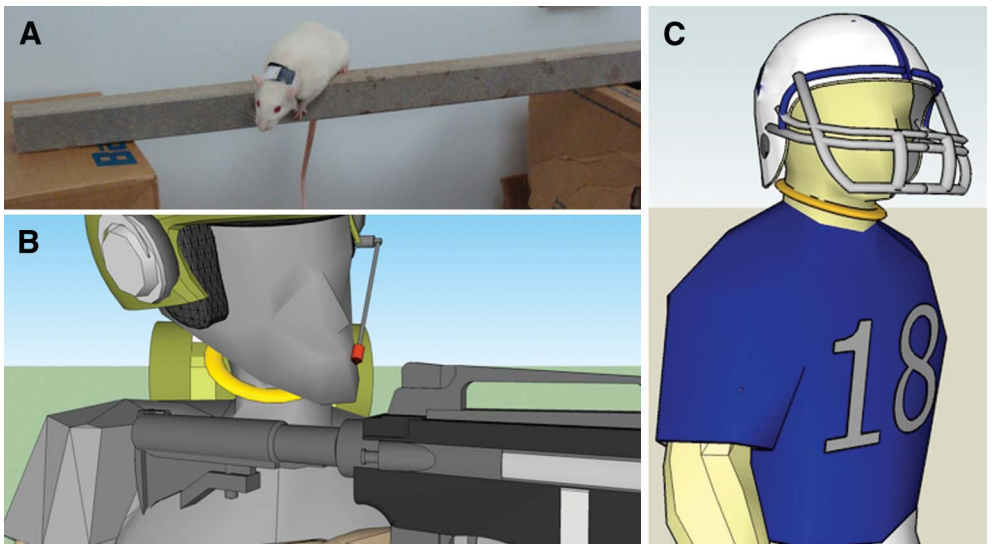

FIGURE 7. *The internal jugular vein compression device.* **A**, *actual device used in this study applied to a rat traversing a balance beam. No observable changes in behavior were noted after collar application with the rat.* **B** *and* **C**, *artistic renderings of a comparable device applied to a soldier on the battlefield and an athlete on the football field, respectively.*

mechanisms are all reminiscent of preventing slosh. It restricts eye movement by closing its thick inelastic eyelids on impact. A pectin structure within the globe increases pressure and volume and thus prevents relative movement of the vitreous and retina. Its cerebrospinal fluid space is remarkably small, resulting in low intracranial volume compliance. Finally, woodpeckers have a hyoid and omohyoid structure similar to that in humans.[18] Because of the direct proximity of the omohyoid atop the IJVs, it is intriguing to speculate that, on contraction of the omohyoid, perhaps with each peck, the IJVs may be partially occluded and intracranial compliance exhausted.

Limitations

This was a pilot and proof-of-concept study that had sufficient power to identify a difference between the treatment and control groups in a cohort of 20 animals because of the magnitude of the difference in outcome. This is a standardized measure of axonal injury that may or may not be translatable to other types of trauma and axonal damage in rats, much less other species, including humans. Nevertheless, the immunohistochemical technique we used is specific for axonal damage and results in a reliable range of measured damaged neurons. In addition, the Marmarou et al[4] model of acceleration-deceleration injury is an accepted and well-studied methodology by which to quantify the extent of TBI with which we and others have published experience.[6-8] A hallmark of this model is the ability to cause diffuse axonal injury as a consequence of not only the initial impact but also the rebound experienced after injury as the animal is placed on a foam pad with known spring constant. An essential component of this is an unimpeded range of motion of the head and neck regions in particular. The IJV compression device used in this work (Figure 7), composed primarily of an elastic band with compression beads overlying the IJVs rather than a rigid material, did not impair or alter the biomechanics of the model. The reduction in damaged axons, as evidenced by a marked reduction in APP counts, in the experimental group with the IJV compression device is highly statistically significant ($P < .01$).

Additionally, we measured the change in ICP after applying the collar in 5 rats. There may have been a variation of increase in ICP in the remaining test rats, but if anything, this would be expected to reduce the variability within experimental groups. Our results show that every study rat had a reduction in axonal injury greater than the 95% confidence interval of the control group. We did not test the protective effect of increasing intracranial volume from blast injury; however, the rationale for its effectiveness is the same.

CONCLUSIONS

Venous compression in the neck reduced the extent of axonal injury in a standardized mild TBI model in rodents. We suggest that our mechanism restricted brain venous drainage and increased its blood volume, thus shifting intracranial physiology to the steep part of the volume-compliance curve. The lack of compliance inside the confines of the skull and spinal canal prevented slosh energy absorption and the resultant axonal injury by causing them to approach a more elastic collision when the skull was struck during the weight drop method. Further research is needed to ascertain whether higher species, including humans, may benefit from slosh mitigation during TBI.

Disclosure

Dr Smith is stockholder and IP owner with Traumatic Brain Injury Innovations. Dr Fisher receives royalty for licensing-related technology from Traumatic Brain Injury Innovations. The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

REFERENCES

1. Faul M, Wald MM, Coronado VG. *Traumatic Brain Injury in the United States: Emergency Department Visits, Hospitalizations and Deaths 2002-2006*. Atlanta, GA: Centers for Disease Control and Prevention; 2010.
2. Benson BW, Hamilton GM, Meeuwisse WH, McCrory P, Dvorak J. Is protective equipment useful in preventing concussion? A systematic review of the literature. *Br J Sports Med*. 2009;43(suppl 1):i56-i67.
3. Gurdjian ES. Cerebral contusions: re-evaluation of the mechanism of their development. *J Trauma*. 1976;16(1):35-51.
4. Marmarou A, Foda MA, van den Brink W, Campbell J, Kita H, Demetriadou K. A new model of diffuse brain injury in rats, part I: pathophysiology and biomechanics. *J Neurosurg*. 1994;80(2):291-300.
5. Schumacher M, Guennoun R, Stein DG, De Nicola AF. Progesterone: therapeutic opportunities for neuroprotection and myelin repair. *Pharmacol Ther*. 2007;116 (1):77-106.
6. Bailes JE, Mills JD. Docosahexaenoic acid reduces traumatic axonal injury in a rodent head injury model. *J Neurotrauma*. 2010;27(9):1617-1624.
7. Mills JD, Hadley K, Bailes JE. Dietary supplementation with the omega-3 fatty acid docosahexaenoic acid in traumatic brain injury. *Neurosurgery*. 2011;68(2):474-481.
8. Mills JD, Bailes JE, Sedney CL, Hutchins H, Sears B. Omega-3 fatty acid supplementation and reduction of traumatic axonal injury in a rodent head injury model. *J Neurosurg*. 2011;114(1):77-84.
9. Chavko M, Koller WA, Prusaczyk WK, McCarron RM. Measurement of blast wave by a miniature fiber optic pressure transducer in the rat brain. *J Neurosci Methods*. 2007;159(2):277-281.
10. Wang WH, Millar JC, Pang IH, Wax MB, Clark AF. Noninvasive measurement of rodent intraocular pressure with a rebound tonometer. *Invest Ophthalmol Vis Sci*. 2005;46(12):4617-4621.
11. Lee EJ, Park KH, Kim DM, Yoo YC, Kang SH, Kim YJ. Assessing intraocular pressure by rebound tonometer in rats with an air-filled anterior chamber. *Jpn J Ophthalmol*. 2008;52(6):500-503.
12. Ohashi M, Aihara M, Saeki T, Araie M. Efficacy of TonoLab in detecting physiological and pharmacological changes in rat intraocular pressure: comparison of TonoPen and microneedlemanometry. *Jpn J Ophthalmol*. 2008;52(5):399-403.
13. Stone JR, Walker SA, Povlishock JT. The visualization of a new class of traumatically injured axons through the use of a modified method of microwave antigen retrieval. *Acta Neuropathol*. 1999;97(4):335-345.
14. Mills JD, Stone JR, Rubin DG, et al. Illuminating protein interactions in tissue using confocal and two-photon excitation fluorescent resonance energy transfer microscopy. *J Biomed Opt*. 2003;8(3):347-356.
15. Raphael JH, Chotai R. Effects of the cervical collar on cerebrospinal fluid pressure. *Anaesthesia*. 1994;49(5):437-439.
16. Teng C, Gurses-Ozden R, Liebmann JM, Tello C, Ritch R. Effect of a tight necktie on intraocular pressure. *Br J Ophthalmol*. 2003;87(8):946-948.
17. May PR, Fuster JM, Haber J, Hirschman A. Woodpecker drilling behavior: an endorsement of the rotational theory of impact brain injury. *Arch Neurol*. 1979;36 (6):370-373.
18. Rai R, Ranade A, Nayak S, Vadgaonkar R, Mangala P, Krishnamurthy A. A study of anatomical variability of the omohyoid muscle and its clinical relevance. *Clinics (Sao Paulo)*. 2008;63(4):521-524.

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COMMENTS

Translation of kinetic energy into central nervous system parenchymal damage, ie, necrotic cell death and cytoskeletal disruption, is instant and irreversible. Energy translation inside the skull is most severe at the level of tissue density transition. Examples include density transition between the skull and cerebrospinal fluid, between cerebrospinal fluid and cortex, and between cortex and white mater. Rotational and translational acceleration is different in tissues with various tissue densities exposed to the same amount of kinetic energy. Rotational acceleration and deceleration of brain inside the skull may not be preventable by conventional helmets, resulting in axonal damage at the cortical white mater junction, the mere effect of which is global decline in cognition and intellectual function. The present investigators tested the effect of internal jugular vein compression and the resultant intracranial hypertension on prevention of the slosh effect in rat brain in an impact-acceleration injury model. This article indicates that the slosh phenomenon is an important process in diffuse axonal injury, as indicated by the density of β-amyloid precursor protein in brainstem axons. Prevention of the slosh effect lowered the number of amyloid precursor protein–positive axons by up to 80%. On the basis of this preliminary study, the investigators suggest that a mild degree of internal jugular vein compression causing intracranial hypertension during an accident might prevent the slosh effect and cytoskeletal injury. The social impact of a workable structural design of future protective helmets mitigating the slosh effect of trauma on intracranial structures might be significant, bringing us 1 step closer to interrupting the devastating effects of trauma on cognitive and intellectual activities of traumatic brain injury victims.

Bizhan Aarabi
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This article provides a method for partially compressing the jugular vein for the purpose of reducing posttraumatic brain damage (eg, amyloid precursor protein staining of brainstem axons) in the rat impact-acceleration model. The authors show how this may be translated to human traumatic brain injury in athletes and soldiers. Although the technique holds promise, compliance remains a potential problem. However, the "slosh" effect and its reduction by the neck collar deserve further study.

Edward D. Hall
Lexington, Kentucky

In this study, the authors describe a method of brain protection via internal jugular vein compression. They observed an impressive reduction in the extent of axonal injury in this model of mild traumatic brain injury in rodents. The authors suggest that by restriction of venous drainage and a subsequent increase in central nervous system blood volume and pressure, brain compliance is reduced. They conclude that it is this lack of compliance that reduces brain slosh.

Although just preliminary, these are interesting observations. The mechanisms underlying the observed brain protection need to be explored further. However, if this translates to human studies, we could potentially explore new avenues of traumatic brain injury prevention, particularly for athletes and military personnel. Could there be pharmacologic agents that modulate brain compliance for a limited period of time, offering increased protection for the duration of a game or on the battlefield? The idea of a protective "jugular collar" is an intriguing one, and only time will tell whether the impact of such a device could prove to be as significant as the benefit we have seen with helmets in traumatic brain injury.

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