

IMPAIRED CEREBRAL AUTOREGULATION AFTER MILD BRAIN INJURY

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BACKGROUND

Severe head injury may impair cerebral autoregulation, which can increase the risk of secondary neuronal injury. The likelihood of impairment in autoregulation is assumed to be low with mild head injury. We report here the absence of cerebral autoregulation in a patient who suffered a concussion from an automobile accident 6 days earlier.

METHODS

The patient participated in a clinical study approved by the institutional human subjects review committee, investigating the dose-effect relationship of anesthetics on cerebral autoregulation. The patient was scheduled to undergo repair of a knee injury suffered during a motor vehicle accident, during which she had a concussion. The screening evaluation revealed no evidence of neurologic disease. The test was to be performed three times in each patient: baseline autoregulation measurements during stable fentanyl-nitrous oxide anesthesia, second and third measurements during low dose and high dose of the anesthetic to which the patient was assigned. Autoregulation was tested by increasing the mean systemic blood pressure from 80 mm Hg-100 mm Hg using a phenylephrine infusion while simultaneously recording flow velocity from a middle cerebral artery using transcranial Doppler ultrasonography.

RESULTS

Static autoregulation testing during baseline testing demonstrated complete absence of this homeostatic mechanism and the study was canceled. Repeated testing in the recovery unit after the patient awoke showed identical results.

CONCLUSIONS

Trivial mild head injury may result in loss of cerebral autoregulation. A clinical study of a larger series to document the incidence is warranted. © 1997 by Elsevier Science Inc.

KEY WORDS

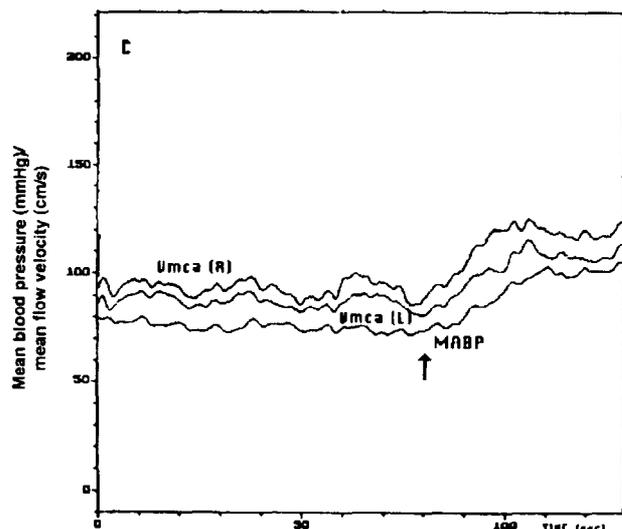
Brain, head injury, autoregulation, cerebral blood flow velocity, equipment, transcranial Doppler ultrasonography, sympathetic nervous system, pharmacology, phenylephrine.

This 29-year-old woman presented for secondary knee repair 6 days after she was hit by a motor vehicle, as a pedestrian. She suffered a brief concussion, and at the time of hospital arrival was noted to be alert without focal neurologic abnormalities. She was noted to be somewhat confused and disoriented. Her computed tomography (CT) scan was normal with no abnormalities of the basal cisterns, to suggest increased intracranial pressure. Her medical history and her physical examination, including neurologic examination, were otherwise unremarkable.

The patient's disorientation cleared within 24 hours, and she was discharged. At the time of admission for the knee repair, she was neurologically normal, on no medications, and denied loss of consciousness at the time of the accident. No preoperative medication was given before anesthetic induction. The anesthetic procedure was as follows: routine monitors including electrocardiogram, pulse oximetry, end-tidal capnometry, and a noninvasive blood pressure monitor were placed. Anesthesia was induced with thiopental 5 mg/kg, fentanyl 3 µg/kg, and vecuronium 0.1 mg/kg; and the patient was mechanically ventilated for normocapnia after the trachea was intubated. Anesthesia was maintained with 70% nitrous oxide in oxygen and fentanyl at 3 µg/kg/hour as a continuous infusion. Once the patient was anesthetized, invasive blood pressure monitoring was instituted and the middle cerebral arteries were insonated bilaterally using a transcranial Doppler (Multi-Dop by DWL, Sipplingen, Germany). The patient's vital signs had been stable before measurements, and specifically there

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1 Static autoregulation tests for baseline measurement (nitrous oxide and fentanyl). Impaired static autoregulation is demonstrated by a completely pressure-passive Vmca paralleling the phenylephrine-induced MABP increase. The slight difference in the right and left Vmca is the result of a different MCA segment insonation. The scale in the vertical axis represents velocity in cm/second or mean blood pressure in mm Hg. The arrow indicates commencement of phenylephrine infusion.

was no systemic hypotension. At a baseline mean arterial blood pressure of 80 mm Hg and PaCO₂ of 38 mm Hg, static autoregulation was measured [1]. Autoregulation testing was performed by inducing a 20 mm Hg increase in mean arterial blood pressure (MABP) with an intravenous infusion of 0.01% phenylephrine. The static autoregulatory response was calculated from the normalized MABP and Vmca value, with the autoregulatory index (AI) defined as:

$$AI = \% \Delta CVR \div \% \Delta MABP,$$

$$\text{where } \% \Delta CVR = (CVR_2 - CVR_1) \div CVR_1,$$

$$\text{and } \% \Delta MABP = (MABP_2 - MABP_1) \div MABP_1$$

% Δ CVR = percentage change in cerebral vascular resistance; % Δ MABP = percentage change in mean arterial blood pressure; CVR₁ = cerebral vascular resistance before elevation of BP; CVR₂ = cerebral vascular resistance after elevation of BP; CVR = MABP \div Vmca; Vmca = middle cerebral artery blood flow velocity. Therefore, perfect cerebral autoregulation would result in an AI of one, and conversely absent autoregulation would result in an index of zero.

The static autoregulatory test for this patient is displayed in Figure 1. During baseline anesthesia,

i.e., during nitrous oxide-fentanyl anesthesia, increasing MABP normally results in little or no change in Vmca [1]. In this patient, however, Vmca exhibited a completely pressure-passive response with the pharmacologically induced MABP increase, indicating an absence of cerebral autoregulation. In order to exclude any potential influence of nitrous oxide and/or fentanyl on our autoregulatory results, the static autoregulatory testing was repeated postoperatively in the awake patient in the recovery room. An identical absence of autoregulatory response with an index of zero was recorded.

DISCUSSION

Most research in the field of traumatic brain injury has been directed toward improvement in understanding of the epidemiology, pathophysiology, and management of severe brain injury. Mild to moderate insults have traditionally received less attention despite their greater overall incidence [2,3]. Because of the apparent lack of neurologic signs, mild head injury is seldom investigated, and pathophysiologic changes are therefore unknown. Its relative importance may easily be underestimated, or it may go unrecognized, as it frequently occurs in association with injury to other organ systems.

Although mild brain injury is not defined uniformly—different clinical parameters, including Glasgow Coma Scale score (13–15), interval of unconsciousness, and period of posttraumatic amnesia are utilized. The reported patient was observed to be in a disoriented and confused mental state after the brief period of unconsciousness at the time of the accident. However, in the context of the knee injuries for which operative treatment was required, the previous history of a mild brain injury was not realized or even mentioned in the admission note. Although the brain injury was clearly of a mild nature, the patient demonstrated a complete absence of the ability to autoregulate cerebral blood flow.

Many trauma patients suffer a mild or moderate brain injury. The fact this often is not recognized as brain injury exposes these patients to a special risk for secondary brain damage. The cerebral autoregulation is the mechanism that maintains a constant cerebral blood flow during changes in cerebral perfusion pressure. Hypoxia and arterial hypotension often occur in trauma patients and may have more detrimental effects if autoregulation is impaired. Although not well documented, most anesthesiologists are aware of anecdotal experience of delayed recovery of consciousness following a nonneuro-

surgical procedure in previously neurologically normal patients with history of mild head injury. Independent of the severity of brain injury, knowledge of an altered cerebrovascular response to changes in arterial blood pressure is of great importance in the anesthetic management of these patients. Maintenance of an adequate cerebral perfusion pressure is imperative; a decrease in blood pressure might provoke cerebral ischemia, whereas an increase in blood pressure might aggravate cerebral edema.

Cerebral autoregulation is known to become impaired after a wide variety of systemic and cerebral insults, including traumatic brain injury. Available data in the literature on cerebral autoregulation after brain injuries are confusing. Findings in children [4] and adults [5] assume an absent autoregulation with severe injury. However, autoregulation had also been found to be intact during the first few days of brain injury and only later deteriorated temporarily [6,7]. Much of the discrepancy between different brain injury studies might be explained by the heterogeneity of the clinical material and principles of treatment in the acute phase of brain injury. The unpredictability regarding the ability to autoregulate in patients with severe traumatic brain injury was recently confirmed by Bouma et al. [8]. Moreover, most of these findings pertain to severe brain injuries exclusively and no such data are available about mild brain injuries.

It is known from animal studies [7] that, in contrast to CO₂ response, which is generally preserved, cerebral autoregulation is very sensitive to brain damage [9]. Injury insufficient to impair other manifestations of circulatory or neurologic function has been shown to disturb cerebral autoregulation [10]. In this sense, the finding of a defective cerebral autoregulation in the reported case is not entirely surprising.

Potential criticisms of this report include the use of nitrous oxide/fentanyl anesthesia in the initial study of cerebral autoregulation. Nitrous oxide and opioids, however, as we have documented in a series of patients, do not disturb cerebral autoregulation [1]. Corroborating our findings, cerebral autoregulation in humans was found to be preserved during nitrous oxide (70%) anesthesia [11]. In alfentanil-anesthetized animals, cerebral autoregulation was found to be similar to that in animals anesthetized without opioids [12]. Moreover, we repeated the study 1 hour after the patient had emerged from anesthesia, and the results were the same. It is doubtful that residual inhalation anesthesia can impair cerebral autoregulation, as low dose inhalation anesthesia preserves cerebral au-

to-regulation. We also consider the possibility that this patient may have absent cerebral autoregulation unrelated to mild head injury. This is deemed highly unlikely as it is inconsistent with normal physiology and not supported by documented evidence of cerebral autoregulation in normal individuals [1].

CONCLUSIONS

In conclusion, our findings suggest that cerebral autoregulation may be substantially impaired after even mild brain injury. The incidence of such occurrence is presently unknown and is the subject of an ongoing study using dynamic cerebral autoregulation testing. At present, there is a greater awareness that significant sequelae may result after these injuries, and our data may contribute to the provision of an effective treatment in order to prevent the occurrence of future disability in these patients.

REFERENCES

1. Strebel S, Lam AM, Matta BF, Mayberg TS, Aaslid R, Newell DW. Dynamic and static cerebral autoregulation during isoflurane, desflurane, and propofol anesthesia. *Anesthesiology* 1995;83:66-76.
2. Langfitt TW, Gennarelli TA, Obrist WD, Bruce DA, Zimmerman RA. Prospects for the future in the diagnosis and management of head injury: pathophysiology, brain imaging, and population-based studies. *Clin Neurosurg* 1982;29:353-76.
3. Anderson DW, McLaurin RL. The national head and spinal cord injury survey. *Neurosurgery* 1980;53:1-43.
4. Kasoff SS, Zingesser LH, Shulmann K. Compartment abnormalities of regional cerebral blood flow in children with head trauma. *J Neurosurg* 1972;36:463-70.
5. Enevoldsen EM, Jensen FT. Autoregulation and CO₂ responses of cerebral blood flow in patients with acute severe head injury. *J Neurosurg* 1978;48:689-703.
6. Cold GE, Jensen FT. Cerebral autoregulation in unconscious patients with brain injury. *Acta Anaesthesiol Scand* 1978;22:270-80.
7. Paulson OB. Regional cerebral blood flow in apoplexy due to occlusion of the middle cerebral artery. *Neurology* 1970;20:63-77.
8. Bouma GJ, Muizelaar JP, Bandoh K, Marmarou A. Blood pressure and intracranial pressure-volume dynamics in severe head injury: relationship with cerebral blood flow. *J Neurosurg* 1992;77:15-19.
9. Gordon E, Bergvall U. The effect of controlled hyperventilation on cerebral blood flow and oxygen uptake in patients with brain lesions. *Acta Anaesthesiol Scand* 1973;17:63-69.
10. Agnoli A, Fieschi C, Bozzao L, Battistini N, Prencipe M. Autoregulation of cerebral blood flow. *Circulation* 1968;38:800-12.
11. Smith AL, Neigh JL, Hoffman JC, Wollman H. Effects of

general anesthesia on autoregulation of cerebral blood flow in man. *J Appl Physiol* 1970;29:665-9.

12. McPherson RW, Kremphasanka E, Eimerl D, Traystman RJ. Effects of alfentanil on cerebral vascular reactivity in dogs. *Br J Anaesth* 1985;57:1232-8.

COMMENTARY

This paper reports an observation in a single patient which, if confirmed on further studies, has important implications not only for the management of less severe head injury, but also for the management of multiple trauma. The authors report evidence of impaired cerebral autoregulation both intraoperatively and confirmed postoperatively in a 29-year-old who had sustained a "minor" head injury 6 days previously and who was undergoing delayed surgery for a traumatized knee.

Although the brain injury was clearly mild, with resolution of confusion after 24 hours, and a CT scan was normal, the observed failure of autoregulation shows just how sensitive this homeostatic mechanism might be following even minor head trauma. One problem for neurosurgeons is the heterogeneity of what constitutes a "minor" head injury based on the Glasgow Coma Scale alone [1]. If subsequent investigations confirm that impairment of cerebral autoregulation may follow such minor head injuries, then, as the authors indicate, particular attention will need to be given to resuscitation and fluid management with provision of hypotension, especially in cases of multiple trauma where a less severe head injury has occurred. Secondary brain damage through hypoxia or hypotension should be almost entirely preventable in this group. Impairment of autoregulation has been identified with a variable incidence in the severely head injured, and it seems unlikely that all or even a majority of patients with a mild head injury will be so affected. But the fact that it may occur in this group

where the outcome should be excellent is an important observation and worthy of further study.

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REFERENCE

1. Culotta V, Sementilly M, Gerold K, Watts C. Clinicopathological heterogeneity in the classification of mild head injury. *Neurosurgery* 1996;38:245-50.

Dysautoregulation in minor head injury is unusual, because disturbed autoregulation and CO₂ reactivity are believed to be grave signs found in severe head injury. The authors happened to discover this phenomenon by Doppler ultrasonography in a case of a seemingly normal person 6 days after concussion. Since I have no experience with Doppler ultrasonography, I am not certain if the blood flow velocity of the middle cerebral artery represents the whole event. Assuming the authors' theory is correct, it seems better to confirm this finding by conventional methods which many institutions use in cerebral blood flow studies. In this case, the presence or absence of dysautoregulation has no clinical importance in the emergency management of injured persons. This paper is an important contribution in that it sheds light on the question of the source of dysautoregulation and the pathophysiology of minor head injury. The definition of concussion, for instance, is broad and variable. Clarifying the essentials of minor head injury will be beneficial to all.

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