Subarachnoid Hemorrhage: Complications Associated with Continuous Cerebral Spinal Fluid Drainage

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Objectives

• Define the basic pathophysiology of subarachnoid hemorrhage
• Identify the structural elements and historical development of the Monroe-Kellie Doctrine
• Discuss the literature on cerebral spinal fluid diversion to reduce vasospasm following subarachnoid hemorrhage.

Disclosures

• Research Funding: Integra Neuroscience
• Research Funding: Medtronic
• Editor-in-Chief: Journal of Neuroscience Nursing
• Board of Directors: Neurocritical Care Society
• Speaker’s Bureau: The Medicines Company
• Speaker’s Bureau: Bard Inc.

I was trained as a scientist

Question Everything

You never prove anything

Saline Lavage

Speaker Disclosures

• I disclose that I am a research grant recipient “Integra Foundation” and “The Agnes Marshal Walker Foundation” and “Neuroptics.”
• I am a member of the “Bard Medical” and “Medicines Company” speaker’s bureau.
• I am the Editor-in-Chief for the Journal of Neuroscience Nursing
• I am on the Board of Directors for the Neurocritical Care Society

Am I (possibly) a heretic there is a lot of controversy

First, let me try to soften the blow by explaining myself (a bit)
Narrowing of blood vessels → reduces blood flow to distal areas → can cause ischemia
• Develops 3-14 days after bleed with Day 6-10 being the most common
• Can develop up to Day 21
• If Fisher grade (>3), risk of vasospasm

Vasospasm can lead to STROKE

Why do we Care?

Why is vasospasm an ischemic stroke?
**Why do we Care?**

Why is vasospasm an ischemic stroke?

**Why is vasospasm an ischemic stroke?**

**CSF diversion following SAH**

- 2004 – Klimo et al
- 2012 – Al Tanimi et al
- z

**Inagawa, Kamiya, Matsuda (1991)**

Effect of continuous cisternal drainage on cerebral vasospasm

*Acta Neurochirg 112(1-2): 28-36*

- Observational study
- No comparison group
- Drainage and irrigation was performed using EVD
- Peri-chiasmatic
- Sylvian fissure
- Interhemispheric fissure
- Irrigation with Lactated Ringers (500-1,100 ml/day)

Patients with Grade III-IV SAH who had 1,000 – 5,500 ml drainage + irrigation had less vasospasm and higher "good" recovery.

**Klimo et al (2004)**

Marked reduction of cerebral vasospasm with lumbar drainage of cerebrospinal fluid after SAH.

*J Neurosurg. 100(2): 215-224.*

- Observational study (1994 – 2003) from 266 SAH cases, 167 patients were included in the analysis (81 had a lumbar drain)
- Patients with **Lumbar drain** had less vasospasm (51% vs 17%)

43 of the 86 'control group' patients had an E.V.D.

a.k.a. = 50% of pt's with worse outcome Had an EVD
I.C.P. → the basics

1. The skull is a closed box
2. The Monro-Kellie doctrine says there are 3 things inside that box (blood, brain, CSF).
3. A change in the volume of the intracranial contents will cause a change in intracranial pressure.

Why did they get EVD?
If the lumbar drain was to get blood out
What was the EVD for?

Lectures on the American Eclectic System of Surgery

Regarding Ventriculostomy:

“This is one of the questionable operations, which though resorted to from the earliest records of surgery, has been followed with so little success that it is not generally recommended - even as a last resort.”

Dr. Benjamin Hill
c. 1850

Monro-Kellie Doctrine

- The sum [brain + CSF + blood] is constant within the skull.
- An increase in one should cause a decrease in one or both of the other two.

Implied → increased ICP is the result of inability of the body to compensate for an increase in one of the three substances

A Brief history of ICP monitoring

Early Interpretations of Intracranial Dynamics

“For, being enclosed in a case of bone, the blood must be continually flowing out of the veins, that room be given to the blood which is entering by arteries. For, as the substance of the brain, like that of other solids or our body, is nearly incompressible, the quantity of blood within the head must be the same, or very nearly the same, at all times, whether in health or disease, in life or after death, those cases only excepted in which water or other matters is effused, or secreted, from the blood vessels; for in these, a quantity of blood, equal in bulk to the effused matter, will be pressed out of the cranium.”

Observations on the structure and functions of the nervous system
1783
Alexander Monro (primus)

Note: this discusses only blood (blood-flow), brain, and bone. & There is no mention of pressure – nor of CSF.
Meanwhile . . . . In Scotland . . . .

John Monro (1670-1740) – Surgeon “First Professor of Anatomy & Surgery” Edinburgh

Alexander Monro primus (1697-1767) – Surgeon (published 8 volumes of “Bones in General”)

Alexander Monro secundus (1733-1870) – Surgeon (he’s the “Foramen of Monro” guy)

Alexander Monro tertius (1773-1859) – Surgeon (Crazy & Cranky)

Dr. Alexander Monroe (tertius)

Loved dissection... Anatomy is “hot” (they dropped the trailing “e”) – Healthy people were murdered to supply cadavers for his anatomy course. One of the murderers was then hanged and Monro decided that murderer would be dissected publicly

• one LATER FAMOUS student was not pleased

Dr. George Kellie

• Kellie ‘estimated’ the amount of blood in the cerebral veins of humans and animals who died in various ways (drowning, hanging, bleeding to death...etc) and concluded that the amount of blood ‘estimated’ in the brain was always ‘about’ the same.

• Working with Monro Secundus!

• Then!!! Kellie found 3 dead guys (shipwreck) and autopsied 2 of them (N=2). There was blood in the veins...but not in the arteries.

• Conclusion: Brain swelling stops blood flow” (I paraphrased)

Dr. John Abercrombie

• 1828 publishes “Pathological and practical researchers on disease of the brain and spinal cord” – This work synthesizes the ideas from Monro’s paper with the ideas from Kellies paper

• Abercrombie totally gives credit to his Doctrine being based on the works of Monro and Kellie

A Brief history of ICP monitoring

Early Interpretations of Intracranial Dynamics

The brain itself, little compressible, is contained within a firm and unyielding case of bone, which exactly fits, and by which it is defended from the weight and pressure of the atmosphere – a force constantly acting on every part of the system – a force therefore which must be constantly operating to maintain the plentitude of the vascular system with the head. If these premises be true, it does not then appear very conceivable how any portion of the circulating fluid can ever be withdrawn from within the cranium, without its place being simultaneously occupied by some equivalent; or how anything new or exuberant can be intruded without an equivalent displacement.

“A brief account of the appearances observed in the dissection of two of three individuals presumed to have perished in the storm of the 3rd, and whose bodies were discovered in the vicinity of Leith on the morning of the 4th, November 1821: With some reflections on the pathology of the brain.”

Transactions of the Medico-Chirurgical Society of Edinburgh 1824;1:82

Kellie discusses pressure as external to the brain – the skull protects the brain from pressure.

Kellie does not mention CSF.

A Brief history of ICP monitoring

Early Interpretations of Intracranial Dynamics

• Prior to Magendie, the only thing we cared about was volume of the intracranial contents.

• Magendie ‘discovered’ CSF and noted that CSF escaped during a spinal tap. Thus, he added pressure to the equation.

Much of this discovery is credited to Magendie’s work with infants !!!!
Cerebral Spinal Fluid

- 400 BC – Hippocrates described fluid in the brain when discussing congenital hydrocephalus as "water" surrounding the brain.
- 200 AD – Galen finds 'excremental liquid' in the ventricles being purged through the nose.

During the "dark ages" and for about 1600 years, the head is severed from the neck for dissection. Thus, the "water" leaks out and the concept of CSF is lost to history until...

Dr. Francois Magendie

- 1824 – Magendie "discovers" a cerebral spinal fluid which is secreted by the pia mater. (oops, got that one wrong)
- 1825 – Magendie formally publishes in 1825!

Magendie was famous for his live public dissections (animals) which many regarded as cruelty. This caused Richard Martin to introduce a bill banning animal cruelty.

Also 1824 - - - - Richard Martin is present when the S.P.C.A. is founded in a London Coffee Shop.

Dr. George Burrows

- 1846 – tests the Monro-Kellie hypothesis including CSF in the equation.
- "depleting the CSF" results in compensation by increased blood.

Intracranial volume = \( \sum (\text{blood}) + \sum (\text{brain}) + \sum (\text{CSF}) \)

Burrows modifies the equation!

Brief History of ICP monitoring

- 1890 – Williams Keen does the first EVD
- 1891 – Quinke uses pipette and LP to measure ICP
- 1903 – Cushing described a triad to recognize elevated brain pressure
- 1948 – Robinson uses a manometer to measure pressure
- 1965 – Lundberg uses a strain-gauge connected to a ventriculostomy.
- 1987 – Richard publishes ICP via fiberoptic device

A Brief history of ICP monitoring

Early Interpretations of Intracranial Dynamics

For almost a century and a half, the hypothesis that the skull and bony coverings of the vertebral canal form a rigid container for the central nervous system has occupied the attention of anatomists, physiologists and neurologists. It is a hypothesis which has been gradually changed in its scope, and even in its conception, since its original promulgation by Alexander Monro in 1783. Having been of interest to many in the course of the first fifty years of its existence, the doctrine has, in the past three decades, again become the subject of intensive investigation by workers in intracranial physiology. It is a tenet which has particularly concerned neurologic surgeons, because on its truth, or relative untruth, depend many of the critical procedures in the surgery of the central nervous system.

Some limitations of the Monro-Kellie Hypothesis

1929

Doctrine?

The Hippocrates-Galen-Monroe-Abercrombie-Magendie-Burrows-Cushing Doctrine states that there are either two or three things that are probably not very compressible inside a box that may or may not be closed and when one or perhaps two of these things takes up more or sometimes less volume then one or two of the other things has to have a reciprocal change in volume or you will have a change in pressure, but we don’t know how much because it’s non-linear. 

Except according to Kellie, this can’t happen because nature abhors a vacuum.

Lumbar drainage of cerebrospinal fluid after aneurysmal subarachnoid hemorrhage has been shown to reduce the prevalence of delayed ischemic neurological deficit and improve early clinical outcome but failed to improve outcome at 6 months after aneurysmal subarachnoid hemorrhage.

Non-randomized because we did not have ‘equipoise’
Rather
We had one MD who said “keep it open”
And
We had one MD who said “Don’t keep it open”
**VISION II Study**

**Prospective - Randomized Single-Blinded**

**Drain-Then-Monitor**

EVD stopcock remains open to drain CSF at a physician-prescribed threshold (e.g. 15 mmHg). It is closed intermittently to monitor ICP.

**Monitor-Then-Drain**

EVD monitoring system is set to a physician-prescribed level & remains closed to monitor ICPs. If the ICP exceeds that threshold for > 5 minutes, the EVD is opened to drain for several minutes, then is clamped again.

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### Table: VISION II Study

<table>
<thead>
<tr>
<th>Variable</th>
<th>Open-EVD (N=34)</th>
<th>Monitor-ICP (N=26)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max ICP</td>
<td>43.92 (19.87)</td>
<td>46.77 (25.32)</td>
<td>0.4687</td>
</tr>
<tr>
<td>CSF Volume</td>
<td>1976 (1501)</td>
<td>1975 (1324)</td>
<td>0.7146</td>
</tr>
<tr>
<td>EVD Days</td>
<td>13.38 (6.41)</td>
<td>15.0 (6.63)</td>
<td>0.4099</td>
</tr>
<tr>
<td>CSF/day</td>
<td>134.99 (109.48)</td>
<td>128.90 (17.29)</td>
<td>0.8348</td>
</tr>
<tr>
<td># of EVDs</td>
<td>1.31 (.48)</td>
<td>1.38 (.65)</td>
<td>0.7445</td>
</tr>
<tr>
<td>LOS (days)</td>
<td>18.92 (10.57)</td>
<td>21.33 (9.07)</td>
<td>0.4715</td>
</tr>
<tr>
<td>mRS</td>
<td>3.62 (2.02)</td>
<td>3.75 (1.57)</td>
<td>0.8232</td>
</tr>
</tbody>
</table>

**Vasospasm**

- Any Method: 22 (64.7%) vs 18 (52.9%) (OR 0.44, 95%CI=0.13-1.45, p=0.1768)
- By TCD: 21 (61.7%) vs 15 (44.1%) (OR 0.72, 95%CI=0.26-2.12, p=0.5486)
- By Angiogram: 7 (20.6%) vs 5 (14.7%) (OR 0.49, 95%CI=0.15-1.56, p=0.2276)
- By CTA: 7 (20.6%) vs 5 (14.7%) (OR 0.49, 95%CI=0.15-1.56, p=0.2276)

**Complication**

- Any complication: 15 (44.1%) vs 6 (17.6%) (OR 3.75, 95%CI=1.21-11.66, p=0.0223)
- Non-Patent EVD: 11 (32.3%) vs 3 (9.4%) (OR 3.85, 95%CI=1.18-12.32, p=0.0276)
- Self-removal: 5 (14.7%) vs 3 (8.8%) (OR 1.21, 95%CI=0.47-3.4, p=0.7755)
- CSF leak/hemorrhage: 1 (3.8%) vs 1 (3.8%) (OR 1, 95%CI=0.34-2.83, p=0.9857)

**Shunt Placement**

- 3 (8.8%) vs 19.2% (OR 0.25, 95%CI=0.09-0.7, p=0.1956)

**Discharge outcomes**

- Discharge mRS <2: 7 (20.6%) vs 5 (19.2%) (OR 1.09, 95%CI=0.3-3.9, p=0.8753)
- Discharge mRS <3: 11 (32.3%) vs 9 (34.6%) (OR 0.90, 95%CI=0.30-2.66, p=0.8753)
- Discharge mRS >4: 15 (44.1%) vs 8 (30.8%) (OR 1.78, 95%CI=0.56-5.29, p=0.2491)
- Died: 8 (23.5%) vs 3 (11.5%) (OR 2.36, 95%CI=0.56-9.96, p=0.2491)

**Complications**

- Any complication: 15 (44.1%) vs 6 (17.6%) (OR 3.75, 95%CI=1.21-11.66, p=0.022). The odds of VSP for the Open-EVD vs Monitor-ICP group was not significant.

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This should look familiar
The results from this study indicate:

There is ONE and only ONE Prospective Randomized Clinical Trial of CSF diversion via EVD following SAH Continuous CSF Drainage is associated with worse outcome no benefit.

Retrospective analysis based on chart audit

Also 62 patients

Lower ICP (5.66 mm Hg) 15.8 mm Hg vs 10.14 mm Hg

IMPORTANT: READ THE METHODS SECTION

So... they concluded that....
Keeping ICP <10 versus >20 Results in lower ICP

We don’t know - - -
- - - probably 10 - - -

Before 2007 the goal was
Drain if and only if the ICP was > 20

After 2007 the EVD was left open at ??????

We don’t know - - - - - - probably 10 - - -

There is no evidence of benefit to continuous CSF diversion

There is EVIDENCE of harm

Thank you

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We did not have time to discuss
- There is no CDE for ICP
- ICP varies over seconds, minutes, hours
- There are huge differences in ICP monitoring
- There is no evidence that CSF drainage reduces ICP
- ICP does not behave as we would predict