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The Origin of Intracranial Pressure Causing Brainstem Hemorrhages

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Abstract

The origin of secondary brainstem hemorrhages following an acute expansive hemispheric lesion has been attributed to Henri Duret, who proposed that hemorrhaging was caused by a shock wave through the cerebral spinal fluid. However, other experiments have shown important findings correlating brainstem hemorrhages to arterial hemorrhages. Animal studies found that the rapidity of expansion of a lesion would be crucial in producing these lesions, but there was no consistent correlation with paratentorial grooving so commonly seen with increased intracranial pressure. This historical perspective studies the different experimentalists who paved the way for the discovery of these secondary brainstem hemorrhages—often named after Duret—and now known not to be invariably associated with poor outcome.

Keywords: Duret, Klintworth, Secondary brainstem hemorrhages, Animal studies, Supratentorial lesion

The experimental studies done to understand and explain the effects of intracranial pressure have typically concentrated on the systemic effects such as the hypertensive surge, bradycardia, and breathing abnormalities, and, much less common, secondary brainstem hemorrhages. Investigators rarely recorded all of these features—many focused on a single, causative explanation. The paucity of monitoring in the earlier experiments may relate to the inability to record physiology; however, others questioned the pathogenesis of secondary brainstem hemorrhage [1]. Parallel to these experimental studies were detailed studies of neuropathological specimens, which suggested that caudal displacement of the brainstem was necessary for the genesis of secondary brainstem hemorrhages. This historical review emphasizes the important work by Gordon Klintworth from Duke University Medical Center, who, in a number of experiments, identified the pathogenesis of secondary brainstem hemorrhages. His work proposed and confirmed a pathogenesis that differed from Duret's hypothesis of a shock wave through the cerebral spinal fluid.

Duret's Contribution

Henri Duret (1849–1921) was a general surgeon who studied arterial circulation in the brainstem and cortex. After injecting solid microparticles of colored gelatin, he was able to study and detail the territorial distribution of each artery. He was the first to describe branches supplying the striatum and thalamus, and the claim has been made that these studies may have led to the theory of cerebral infarcts resulting from thrombosis of a single artery [2].

Duret, however, is best known for his dog (and sometimes horse) experiments, in which he rapidly injected gelatin inside the cranium with the intention of creating *les phenomenes de choc* [3]. He noted acceleration of blood pressure, respiratory arrest, bradycardia, and "tetanisme." He interpreted his experiment as a "cephalic shock," and the oscillation caused displacement of nervous tissue, creating tears in neuronal tracts. In fact, the hemorrhages in the aqueduct of Sylvius (Fig. 1) were explained by Bernoulli's principle, which postulates that

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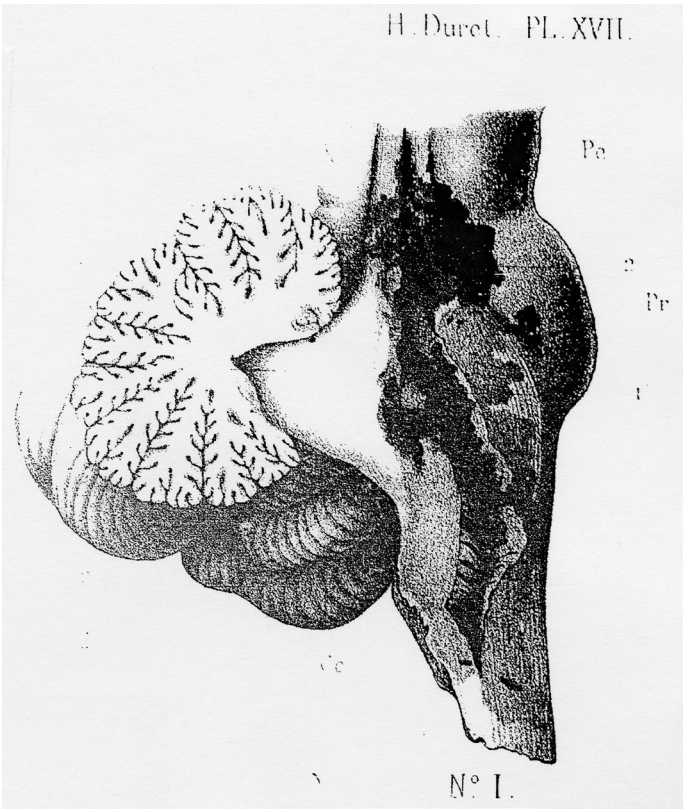

Fig. 1 Duret's hemorrhages in the brainstem

the hydrostatic pressure is degraded in the immediate post-stenotic area. Because he could not find lesions in the cerebral hemisphere as a result of these physiological changes, Duret examined the brainstem and found a significant dilatation of the aqueduct of Silvius through the entire length of the central spinal canal. Duret was not convinced that these hemorrhages were the result of ruptured blood vessels; instead, he argued that the compressed capillaries resulted from significant excess pressure of the cerebral spinal fluid and cessation of the blood flow. Duret found a pressed-down cerebral hemisphere, collapsed ventricular cavity, the medulla flattened against the basal groove and compressed basilar artery and branches and concluded that the medullary circulation was compromised not only due to increased intracranial pressure, but also due to ischemia. Duret's findings in his animal experiments came approximately 25 years before Cushing's observations of the secondary systemic effect associated with suddenly increased intracranial pressure that bears his name.

Klintworth's Contribution

While the animal experiments of Gordon Klintworth are seldom remembered, they did elaborately explain the nature of the brainstem hemorrhages. Klintworth anesthetized 100 mongrel dogs with barbiturates, made a burr hole at different sides in the calvaria, and inflated a Foley catheter into the subdural or epidural space. Balloons were inflated to various sizes (0–24 mm) and at various rates. The brains were removed after death and examined microscopically. Klintworth noted three phases of blood pressure: a relatively stable phase, a subsequent hypertensive phase, and, finally, a terminal period, where blood pressure fell to 0 [4]. The pupils dilated with the rise of blood pressure, and both dilated pupils became fixed at the time of maximal blood pressure. Klintworth was clearly able to identify the period before bilateral fixing of the pupils in which evacuation of the balloon was reversible. However, he also noted the relatively slow expansion to volumes as large as 10 ml was fatal, but did not produce midbrain or pontine hemorrhages. He concluded that the secondary brainstem hemorrhages occurred consistently during the hypertensive phase and concluded that the site of the initial hemorrhage depended on the volume of the intracranial balloon, with smaller volumes capillary and larger ones arterial or venous hemorrhages. Klintworth hypothesized that a large, expanding supratentorial lesion displacing the brainstem downward but

resulting in death during a period of brainstem ischemia, secondary brainstem hemorrhages could not take place (Fig. 2A and B). However, when a supratentorial lesion is evacuated after a downward displacement, and brainstem blood flow is restored, hemorrhages will ensue through the damaged blood vessel (Fig. 2C). Within an acutely, rapidly expanding supratentorial lesion, downward displacement of the brainstem traumatizes blood vessels, but still allows restoration of brainstem flow resulting in secondary brainstem hemorrhages (Fig. 2D).

In a subsequent paper several years later, Klintworth investigated paratentorial grooving of the brain in relation to transitory herniation and secondary brainstem hemorrhages [5]. However, he could not find a direct correlation between the amount of paratentorial grooving or transitory cerebral herniation in the presence or absence of secondary brainstem hemorrhages. He argued that a collar of herniated cerebrum around the brainstem is necessary for development of the hemorrhage, again arguing that secondary brainstem hemorrhages correlate with adequate blood flow after the vasculature is severed from a downward, displaced brainstem.

Pathological studies of patients who died from supratentorial lesions associated with secondary brainstem hemorrhages (Fig. 3) also revealed that supratentorial decompression restores cerebral blood flow and initiates hemorrhages into the brainstem, but only in patients with damaged vasculature to brainstem. In his prospective and retrospective clinicopathological investigation of over 1200 patients with supratentorial expanding lesions, he found that most patients with secondary brainstem hemorrhages had extensive supratentorial hemorrhage or edema, but most of the secondary brainstem hemorrhages occurred in the absence of surgery [5].

Contemporary Views

For many years, the presence of secondary brainstem hemorrhages in a patient following traumatic head injury was considered fatal and an indicator of poor outcome. But pathologists wisely refused to attribute causes in

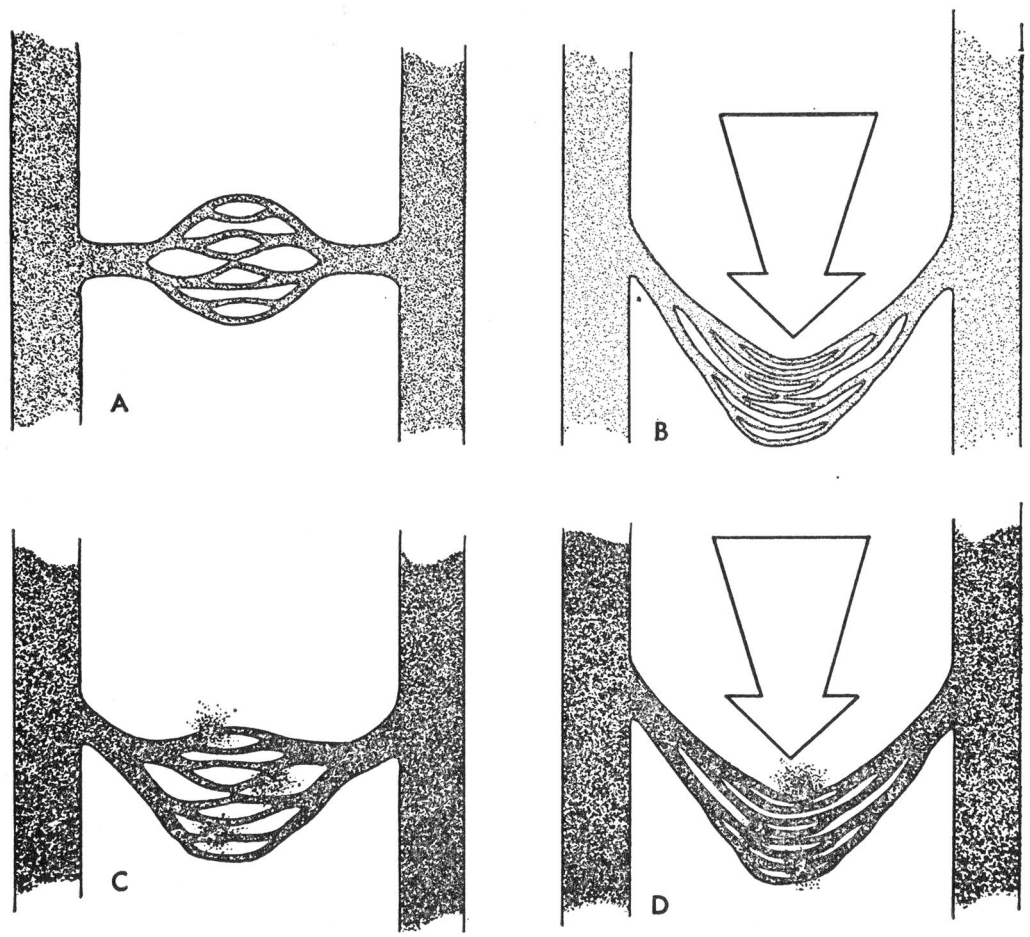

Fig. 2 Klinsworth's mechanism of secondary brainstem hemorrhages (*used with permission of the American Journal of Pathology*)

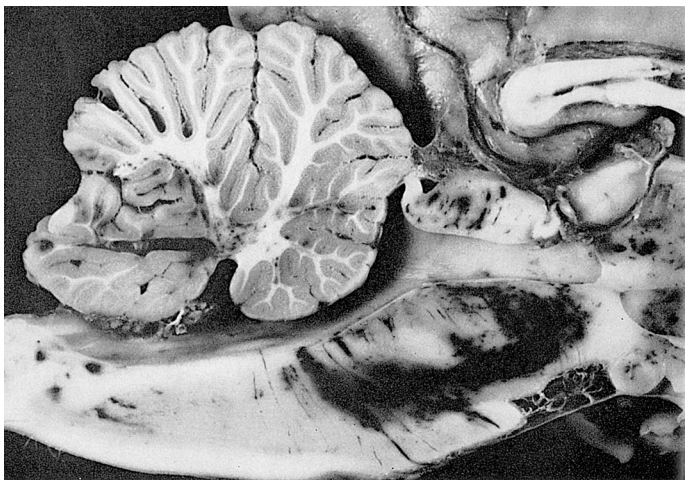

Fig. 3 Pathology of Klintworth's paper showing extensive secondary brainstem hemorrhages in midbrain and pons, but also in cerebellum, thalamus, and hypothalamus as a result of a rapid balloon inflation experiment (*used with permission of the American Journal of Pathology*)

acute brain injury, knowing much happens in intensive care settings. Furthermore, multiple studies have found that recovery is possible. Some studies have found brainstem hemorrhages in 37% of postmortem traumatic head injury of 132 postmortem fatal head injury cases [6]. However, Caplan and Zervas [7] reported two patients with decerebration after severe, traumatic head injury, but survival with relatively preserved cognitive function as well as third-nerve palsies and in a patient with a secondary brain hemorrhage. The distinction between primary traumatic brainstem hemorrhages and secondary hemorrhages has remained difficult in clinical practice. Currently, brainstem hemorrhages are found easily on computed tomography scans and, not infrequently, after decompressive surgery. From an historical perspective, the secondary hemorrhage in the brainstem is important. As we now know, the degree of clinical injury to the brainstem determines outcome.

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