



Research Article

# Brain Tamponade and Cerebral Flow: is Continuous Flow the Answer to overcome it?

Federico Bianchi<sup>1</sup>, Alessandro Rapisarda<sup>1</sup>, Carmelo Anile<sup>1,2\*</sup>

<sup>1</sup>Agostino Gemelli University Hospital Foundation IRCCS, Largo Agostino Gemelli, 8 - 00168 Rome, Italy

<sup>2</sup>Catholic University of the Sacred Heart, Largo Agostino Gemelli, 1, 20123 Milano MI, Italy

**\*Corresponding author:** Carmelo Anile, Agostino Gemelli University Hospital Foundation IRCCS, Largo Agostino Gemelli, 8 - 00168 Rome, Italy

**Citation:** Bianchi F, Rapisarda A, Anile C (2022) Brain Tamponade and Cerebral Flow: is Continuous Flow the Answer to overcome it?. J Surg 7: 1594. DOI: 10.29011/2575-9760.001594

**Received Date:** 04 October, 2022; **Accepted Date:** 07 October, 2022; **Published Date:** 10 October, 2022

## Abstract

**Objective:** This paper aims to suggest how brain circulation in tamponade condition might be restored changing cerebral blood flow characteristics from pulsatile to non-pulsatile.

**Material and methods:** we prepared an animal model in order to create a selective non-pulsatile brain circulation through an external pump. The authors used Doppler and ICP monitoring to check brain tamponade and blood flow velocity in the middle cerebral artery.

**Results:** In our experiment, it is possible to see how passing from normal pulsatile flow to non-pulsatile one, Doppler velocity in brain tamponade condition appear again.

**Conclusion:** such a modification in blood flow typology might represent a hint to overcome brain tamponade in humans. Obviously, this experiment is only the beginning in defining appropriate methods to apply the described methodology in future clinical use.

**Keywords:** Brain tamponade, non-pulsatile flow.

## Introduction

In neurosurgical practice, brain tamponade represents the ultimate limit for treatment. It is defined as a progressive Intracranial Pressure (ICP) increase up to values close to arterial Blood Pressure (BP) producing a reverberating flow pattern in the cerebral arteries with no net flow [1]. Nowadays, patients reaching such a condition are labeled as untreatable due to the lack of effective treatment. Decompressive craniectomy might in peculiar conditions, such as in very little children, overcome the limit thanks to the incredible capability of a still growing brain to recover from extensive injuries but that is not the case in adult or elder patient. Throughout the literature, there are several papers addressing the matter but still no clear advance was proposed. In fact, many of the papers are still at the animal levels also due to the actual difficulties in creating an ethically approvable human

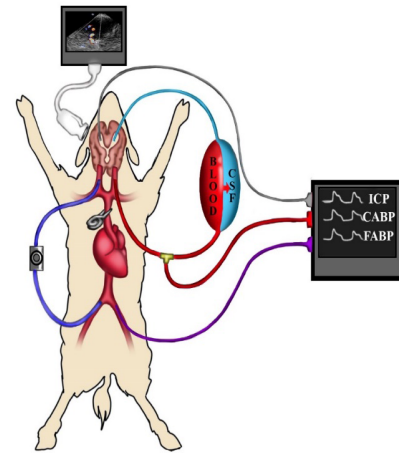
model. This aspect is linked to the fact the patients near brain tamponade conditions must be rapidly treated whenever possible being hard to create a double group-controlled study. Furthermore, it is not so easy to define the actual limit in which brain tamponade become irreversible. The authors themselves, in previous papers, highlighted how even in prolonged brain tamponade conditions, metabolism inside the neuronal cells still continue even after prolonged ischemia time [2,3]. The idea of overcoming the blockage in cerebral blood flow modifying its modality derived from a previous report of residual arterial and venous pulsation even in tamponade brains [1] and in a very old paper by Portnoy, Chopp and Branch (1983) [4]. In this paper they presented an original model of intracranial system in which, directly connecting the internal pressure to the external (intracranial) pressure, thus simulating a hemorrhagic event, the continuous, non-pulsatile flow persists to run, even if at very low level. Based on these considerations, we hereby present a unique experimental animal

model in which changing the modalities of brain blood supply from pulsatile to continuous one, it might be possible to maintain a little cerebral perfusion even in conditions of highly elevated intracranial pressure. The reason of this uniqueness is its extreme complexity in performing the experimental preparation to resolve definitively the answer.

## Material and Methods

A female sheep of 33.2 Kg was sedated using intramuscular Atropine (1 mg) and Ketamine (10 mg/Kg). It was placed supine on the operating table, intubated and anesthetized with Halothane (0,8-1%) and Pancuronium Bromide (0,5 mg/h intravenously administrated). This animal was chosen because its particularity in the anatomy of the aortic arch; in fact, from it sources a unique brachio-cephalic arterial trunk from which the four vessels for the head and for the upper limbs originate; this means that there are about two centimeters of trunk free in which a clamp may be put to consent (open) or to prevent (closed) the blood flow. To this aim, after anesthesia, a thoracotomy was performed to expose the brachio-cephalic trunk to put around it, before the double bifurcation in the four vessels, a cloth tape able to act as a clamp.

Four incisions were made at carotid and femoral arteries levels at both sites; a catheter was put at left femoral artery to record the systemic arterial blood pressure; another catheter was put in the right side to have the possibility to draw blood to be re-inserted, passing through a turbine bio-pump, into the body at the carotid level. A catheter was put into a left carotid artery to record the carotid blood pressure and, by means of a three ways stopcock, to be able to permit the passage of the blood in an empty reservoir strictly connected, within an inextensible bag, to another reservoir full of CSF-mock connected to a catheter put into the left cerebral ventricle. In the right carotid artery, we have put a three ways bypass connected to the bio-pump and permitting the passage of the blood or from the distal part of artery to the proximal part, or the passage from the bio-pump to both sites of artery, distal and proximal ones (Figure 1). In such way we have two possibilities: 1) when the bio-pump is off and the brachio-cephalic trunk is not clamped, the blood flow runs physiologically from the heart to the brain with its normal pulsatility; 2) when the trunk is clamped and the bio pump is on, the blood flow runs in a continuous modality perfusing both the brain and the upper limbs by means of the carotid by-pass. So, when the catheter put in the left carotid artery is open, the blood runs into the empty reservoir that, in turn, press the CSF-mock contained in the other reservoir into the ventricle so producing a “spontaneous brain tamponade condition”, without the deleterious effects of a direct contamination of the blood into the ventricles.



The sheep was evaluated for the whole duration of the procedure using:

- Electrocardiogram (ECG);
- Systemic Arterial Blood Pressure (SABP) measured through a line in the femoral artery;
- Carotid Blood Pressure (CBP) measured through a line in the carotid artery;
- Middle Cerebral Artery Blood Flow Velocity (MCABFV) measured using a doppler ultrasound device placed to an ad-hoc temporal craniotomic window;
- Intracranial Pressure (ICP) measured using an intra-parenchymal sensor (ICP Express Codman) placed into the brain parenchyma using a parietal burr hole.

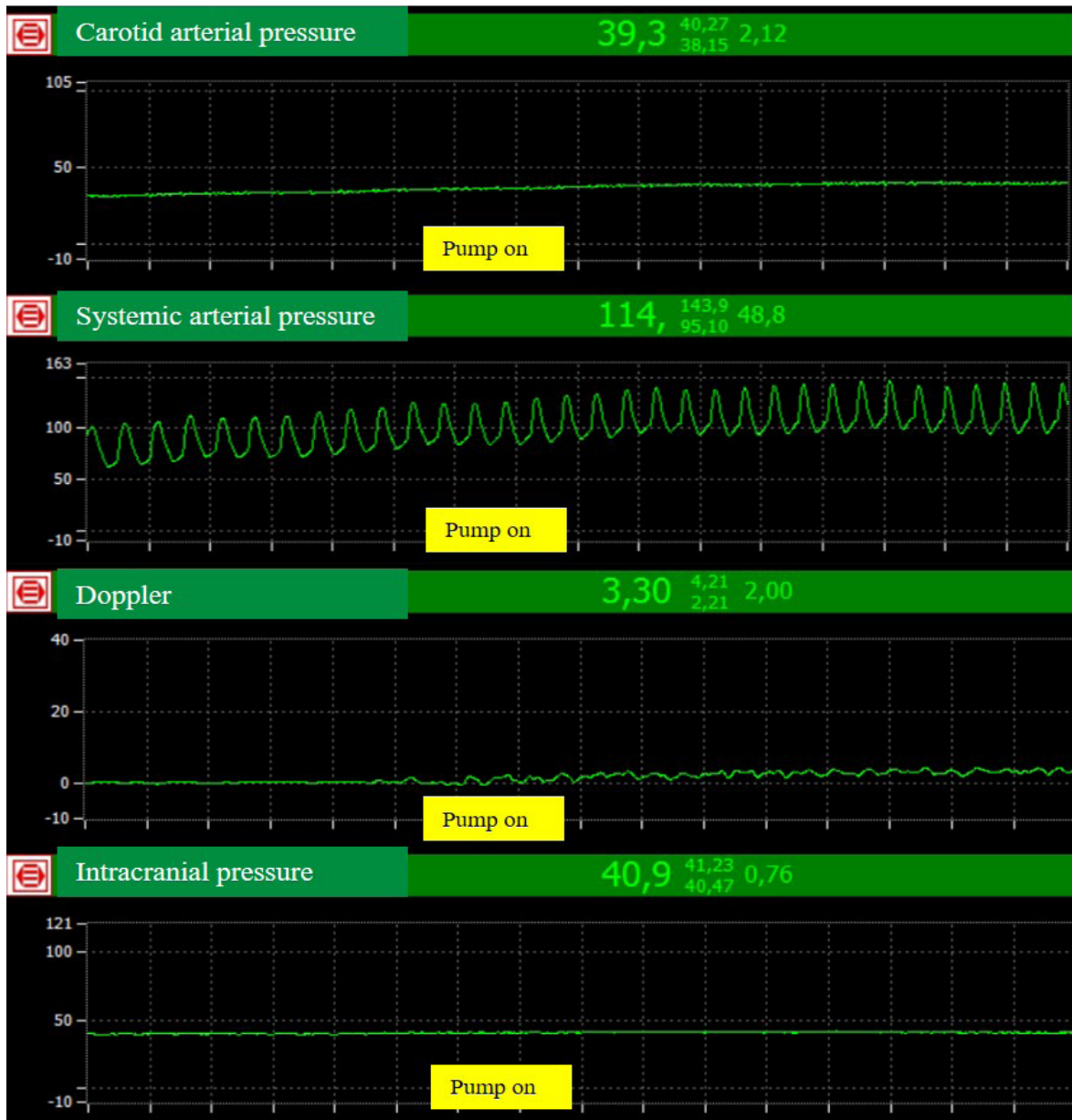
In order to recreate a condition of spontaneous brain tamponade the authors opened the bypass from the blood circulation to the inextensible bag while maintaining pulsatile flow. Doing so blood coming from the systemic circulation would fill the first inextensible bag pushing the mock CSF resting in the second bag into the intracranial system. The center of our experiment resides in the switch in intracranial circulation obtained clamping the aortic arch and activating the extra cerebral brachio-cephalic circulation (ECBCC) while maintain the previously described conditions. Such a change would contemporarily maintain brain tamponade and modify blood flow from pulsatile to continuous. At the end of the experiment, the authors sacrificed the animal while continuing general anesthesia using an intravenous administration of 10-mEq potassium chloride.

## Results

We report in Figures 2,3 the results of the recorded pressures

alongside the experiment. The data reported in those photos represent only the most striking moments alongside the prolonged registration. Figure 2 shows CBP, SAP, flow presence and ICP during brain tamponade. In this case, CBP is 50 mmHg while SAP is 60 mmHg and ICP 47 mmHg. Therefore, net flow measured by intracranial Doppler is practically null (0,94 m/s). On the hand, switching on the ECBCC and thus changing the flow from pulsatile to continuous it is possible to see how blood flow velocity progressively increase to reach 3,30 m/s as a demonstration to flow reappearance.





## Discussion

Throughout the literature, there are very few reports regarding flow typology in intracranial circulation. Such papers are mostly related to intracranial changes after ischemic heart failure. Reviewing the literature trying to select the most fitting papers, only two authors slightly address the problem. The first one only mentions non pulsatile blood flow as something unclear as well as a potential sign for proximal arterial occlusion (Kim et al. 2006) [5], while the other one, suggests the importance of pulsatile flow during reperfusion without addressing at all flow modifications during tamponade [6]. To overcome such a lack of evidence on the matter, the authors devised the presented experiment. The aim was to analyze whether changing cerebral blood flow from pulsatile to non-pulsatile was possible to overcome brain tamponade. Such an experiment was founded on the idea that the very “normal” blood pulsation coupled with Starling resistor functioning is at the base of cerebral tamponade. Physical laws states that flow is driven by the presence of a pressure gradient between two compartments connected by a channel. Thus, as long there is a gradient there will be flow no matter how small the caliber



of the channel will become. Flow stops then after the closure of the channel or after gradient disappearance. The application of such physical law to the intracranial system were evaluated for the first time by Chopp et who created a model simulating the intracranial space and its modifications during volumetric tests [4]. The described physics lead to the presented experiment idea. To understand the peculiarity of the presented work is necessary to underline two of the specifics of the intracranial system. Firstly, venous outflow before reaching the major sinuses has to pass through a narrower gate, namely the Starling resistor and secondly the pressure propagation speed is lower in vessels than interstitial space. Thus, in normal pulsatile flow during diastole, whenever intracranial pressure approximate CBP, pressure waves traveling outside the vessels reach faster the Starling resistor causing its closure despite the growing inlet pressure. Therefore, this mechanism coupled with pressure gradient disappearance leads to brain tamponade.

On the other hand, if the circulation were non-pulsatile a net flow would be always present thanks to the persistence of pressure gradient. The gates will become smaller in an asymptotic way never actually closing and preventing the reach of zero net flow. Obviously, this situation is theoretical and, the gates will eventually close, but with a higher intracranial pressure. To demonstrate such an assumption, we have created a model of selective extracorporeal brachiocephalic circulation to send continuous flow to the brain without affecting body circulation.

We decided to use the sheep model to simplify the experiment having this animal a peculiar anatomy of the brachiocephalic trunk. Such conformation simplifies the experiment granting the selectivity control of the cerebral blood flow through the manipulation of a single vessel. Nonetheless, it is important to remember that collateral circulation might be present in selected cases reducing the power of the experimental model. In the sheep model though, such collaterals disperse most of their contribution to the spinal roots and to the neck muscle making the amount of cerebral distribution negligible.

The authors analyzed and compared the data extrapolated from the continuous recording of the measured pressure in between the different blood flow typology. In first instance, not to miss differences in normal conditions between animals and humans, we recorded CBP, SAP, flow presence and ICP during brain tamponade. As expected when CBP approximate ICP blood flow progressively decrease heading towards zero (Figure 2). In Figure 3 is outlined the ECBCC activation and the subsequent modifications to the

previous recording. In fact, it is possible to see how in contrast with the persistence of the ICP levels close to CBP the transcranial Doppler shows a progressive flow reappearance. Flow increase in continuous blood flow overcome in this way tamponade condition. In a theoretic model, the tamponade resolution should be lasting however, in reality; higher ICP levels would recreate brain tamponade. The most striking data reside in the reappearance of blood flow during brain tamponade after the change from pulsatile flow to continuous one. The data derived from our work represent an interesting opening on further studies on the matter even though it is important to underline how this single animal experiment can only suggest a possible new treatment in brain tamponade.

## Conclusion

Brain tamponade in neurosurgery represents nowadays the terminal line for treatment. Every effort must be made to find a way to overcome such a limit. Our data might represent the first step in that direction showing how changing cerebral flow even tamponade can temporarily overcome. Even though this is only an animal experiment it might open the way to further animal experiment and thus to human ones.

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