doi: http://dx.doi.org/10.11606/issn.1679-9836.v101i6e-196560 Rev Med (São Paulo). 2022 Nov-Dec;101(6):e-196560.

Original Article

Didactic prototype demonstrates the effect of intracranial pressure on cerebral perfusion pressure

Protótipo didático demonstra o efeito da pressão intracraniana sobre a pressão de perfusão cerebral

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Cassani MRM, Guilarducci, VT, Hohl R, Mourão-Júnior CA, Nagato AC. Didactic prototype demonstrates the effect of intracranial pressure on cerebral perfusion pressure / *Protótipo didático demonstra o efeito da pressão intracraniana sobre a pressão de perfusão cerebral.* Rev Med (São Paulo). 2022 Nov-Dec;101(6):e-196560.

ABSTRACT: Cerebral perfusion pressure (CPP) results from the difference between mean arterial pressure and intracranial pressure (ICP). The comprehension of the biophysical principles that explain how ICP influences CPP dynamics requires abstraction and can be explained by analogy using low-cost prototypes. Objective: To come up with a didactic prototype developed with recyclable materials that shows the influence of ICP on CPP. Method: A prototype was built with a 200 ml PET bottle, overpassed by a 06 cm latex ball (standard: 5:150 cm), simulating respectively, the skull and a single cerebral vessel. A 10 ml syringe was connected to the PET in order to reduce the volume of the system and increase the pressure inside it. A latex bulb, containing an unidirectional valve, was connected to the latex ball through a double-lumen tube, in which, one of the branches was used to direct an airflow to the latex ball. To demonstrate the pressure variation inside the PET (ΔP1) and inside the latex ball (ΔP2), two aneroid manometers (M1 and M2, respectively), connected with latex hoses, were used. All connections have been sealed with silicone. Results: The syringe plunger compression reduced the system volume and increased ΔP1 = 30mmHg, resulting in a collapsed ball and increased resistance to the air flow (with an increase of ΔP2 = 30 mmHg in M2) when the bulb was pressed. The perceived handgrip effort to compress the bulb was higher when ΔP1 was increased. The prototype allowed a direct intuitive comparison between the PET/skull and the ball/blood vessel, and it was also possible to see how the elevation of the ICP plays an important role in the CPP. Conclusion: Prototypes with low-cost materials are intuitive and easily accessible tools that can be used to didactically illustrate the fundamental biophysical influence of ICP on CPP in humans.

Keywords: Proof of concept study; Intracranial pressure; Cerebrovascular circulation; Biophysics.

RESUMO: A pressão de perfusão cerebral (PPC) resulta da diferença entre pressão arterial média e pressão intracraniana (PIC). A compreensão dos princípios biofísicos que explicam como a PIC influencia a PPC exigem abstração e podem ser explicados por analogia utilizando protótipos de baixo custo. *Objetivo:* Apresentar um protótipo didático desenvolvido com

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materiais recicláveis que mostre a influência da PIC sobre a PPC. *Método:* Foi construído um protótipo com uma garrafa PET de 200 ml, ultrapassada por 6cm de uma bola de látex (padrão 5:150cm), simulando, respectivamente, o crânio e um vaso cerebral. Uma seringa de 10ml foi conectada ao PET para reduzir o volume do sistema e elevar a pressão no seu interior. Um bulbo de látex, com válvula unidirecional, foi conectado à bola através de um equipo de duplo lúmen, no qual um dos ramos foi utilizado para direcionar fluxo de ar para a bola. Para demonstrar a variação de pressão no interior do PET (ΔP1) e da bola de látex (ΔP2) foram utilizados dois manômetros aneroides (M1 e M2, respectivamente) conectados com mangueiras de látex. Todas as conexões foram vedadas com silicone. *Resultados:* A compressão do êmbolo da seringa reduziu o volume do sistema e aumentou ΔP1 = 30mmHg, implicando colapso da bola, elevação da resistência à passagem do fluxo de ar (com um aumento de ΔP2 = 30mmHg em M2) quando o bulbo era pressionado. Uma maior sensação de esforço manual para comprimir o bulbo foi percebida com ΔP1 aumentado. O protótipo permitiu a analogia intuitiva garrafa PET /crânio e bola/ vaso sanguíneo, sendo possível perceber como a elevação da PIC altera a PPC. *Conclusão:* Protótipos com materiais de baixo custo são ferramentas intuitivas e de fácil acesso que podem ser utilizados para ilustrar didaticamente os fenômenos biofísicos fundamentais da PIC sobre a PPC em humanos.

Palavras-chave: Estudo de prova de conceito; Pressão intracraniana; Circulação cerebrovascular; Biofísica.

INTRODUCTION

Cerebral blood circulation has peculiarities inherent to the fact that blood travels within an anatomical compartment, the skull - a unique fact in the human body that requires the study of specific variables. Cerebral perfusion pressure (CPP) is the pressure of blood during its passage in the cerebrovascular bed[1], and its value is estimated from the result of the difference between intracranial pressure (ICP), the pressure inside the cavity itself, and mean arterial pressure (MAP), which refers to the average between the variation of systolic and diastolic blood pressure over a cardiac cycle[2,3]. Reductions in CPP occur when there is an elevation in ICP, as in cases of venous sinus or jugular vein thrombosis, increased cerebral volume, increased cerebral blood volume, cerebral edema, subdural hematoma, epidural hematoma, cerebral empyema or abscess, hypertensive pneumocephalus[4], and/or when there is a reduction in MAP, for example in cases of orthostatic[5] and postprandial[6] hypotension. On the other hand, increases in CPP occur when MAP is elevated, as in cases of idiopathic hypertension or secondary to renal and endocrine diseases, obesity, and sleep apnea syndrome[7], and/or when ICP is reduced, for instance, in cases of pharmacological agents, such as mannitol or hypertonic saline solution[8].

The stability of CPP with values around 50 mmHg[2] is important to maintain a satisfactory cerebral blood flow (CBF) and ensure the supply of oxygen and nutrients to the central nervous system. Values below 50 mmHg reduce CBF and lead to ischemia - a phenomenon characterized by reduced cerebral perfusion[2,3]. The increase in ICP not accompanied with an increase in MAP reduces CBF[3] by inducing vascular resistance caused through an external force to the blood vessel, which tends to reduce vascular diameter.

In adults, a supraphysiologic elevation of ICP, sustained with values of at least 20 mmHg for more than 20 minutes[2,3,9] characterizes intracranial hypertension (ICH). Although the causes are multivariate, in general, ICH is induced by elevations in CSF volume, blood or brain mass[2,3].

The first to perform ICP monitoring were the French Jean Guillaume and Pierre Janny. The estimated measurement was made by electromagnetic transduction, from ventricular cerebrospinal fluid pressure signals that were generated from the interruption of CSF flow by back pressure[10]. The improvement of new ICP measurement techniques in the clinical area has ensured a more accurate monitoring, with lower risk of infection and bleeding[10,11], which has contributed to the management of patients who need this monitoring.

The complexity of the biophysical and physiological phenomena related to the maintenance of ICP requires a great deal of abstraction from the scholar, especially due to the difficulty in understanding the facts of intracranial invasion. Teaching prototypes have been used as important didactic tools to demonstrate how the isolated phenomena occur in the organism[12,13] and to facilitate the acquisition of knowledge.

The present study aimed to present a didactic teaching prototype produced with recyclable materials that showed the relationship between ICP and CPP and allowed the establishment of analogies with the anatomo-physiological principles involved in the dynamics of cerebral perfusion.

MATERIAL AND METHODS

The prototype was built using: a 200 ml polyethylene terephthalate (PET) container, 06 cm of a 5:150 cm standard latex ball, a 10 ml syringe, two aneroid manometers (M1 and M2), a double-lumen line, latex hoses, and silicone to glue and seal the system (Figure 1).

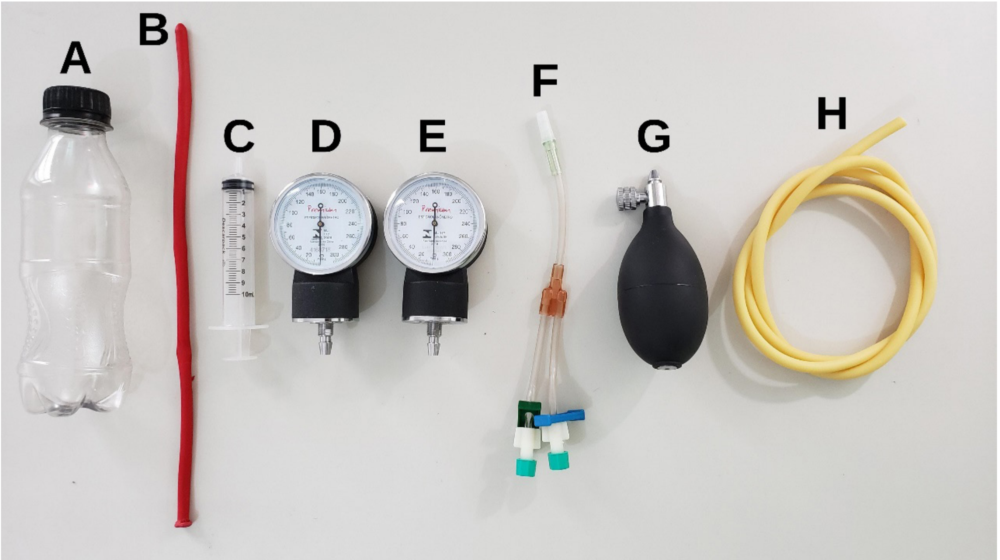

Figure 1 - Materials used to build the prototype. (A) 200 ml PET bottle. (B) Latex ball - standard: 5: 150 cm. (C) 10 ml syringe. (D and E) aneroid manometer - 0 to 300 mmHg. (F) double-lumen line. (G) latex bulb. (H) latex hoses.

Two holes of 6 mm diameter were drilled in the PET to fix the latex ball internally in the PET, one in the central region of the PET base and the other in the central region of the lid. A third hole was drilled in the PET from the bottom to attach a syringe through a hose so that the volume of the PET could be changed and, consequently, its internal pressure modified. A fourth hole was drilled in the middle lateral region of the PET to couple the M1 manometer and allow the measurement of the internal pressure of the PET. From the hole in the lid, a double lumen line was connected to the latex ball. One branch of the line was attached to the latex bulb, containing a one-way valve, and another branch was connected to the M2 manometer, to propel an air flow towards the ball and measure the pressure inside the ball, respectively (Figure 2). All connections were properly sealed with silicone.

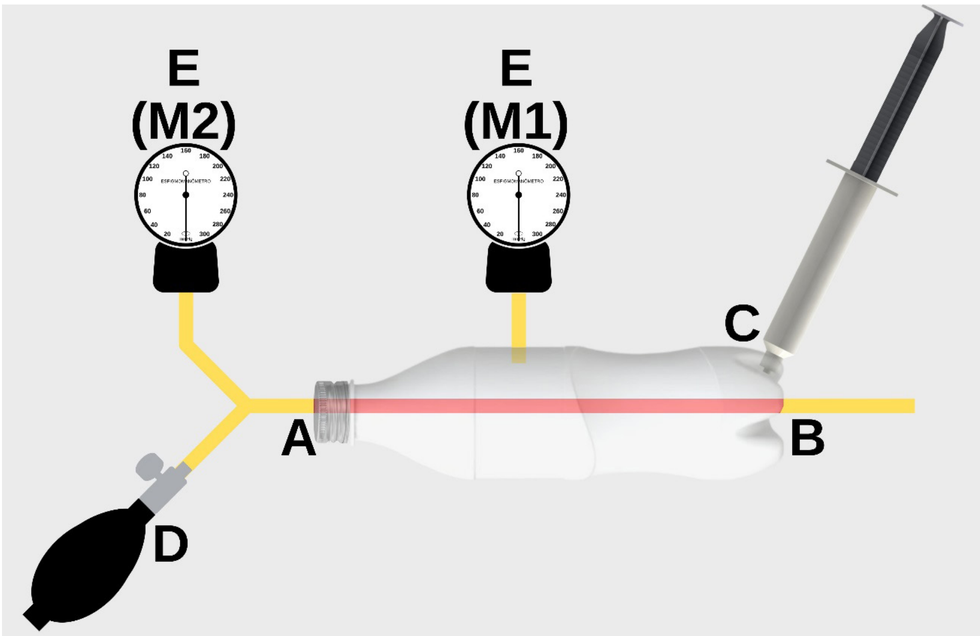

Figure 2 - Idealization of the brain perfusion prototype. (A and B) latex ball attached to the PET through holes in the central region of the lid (A) and lower central region of the PET (B). (C) syringe attached inferiorly to the PET. (D) latex bulb attached to the double-lumen line. (E) manometers M1 and M2 attached, respectively, to measure pressure inside the PET and inside the latex ball.

RESULTS

Each object used in the construction of the prototype was intended to simulate, in a didactic and reductionist way, some important anatomical and functional components involved in the dynamics of cerebral perfusion. The PET represented the skull, the latex ball simulated a single cerebral blood vessel, the syringe was used to induce increased intracranial pressure (analogous to intracranial hypertension), the latex bulb represented the propeller of blood flow to the brain (heart), the space between the latex ball and the PET corresponded to the brain compartment, filled with brain mass and CSF, and the air, contained inside the ball, alluded to blood (Figure 3).

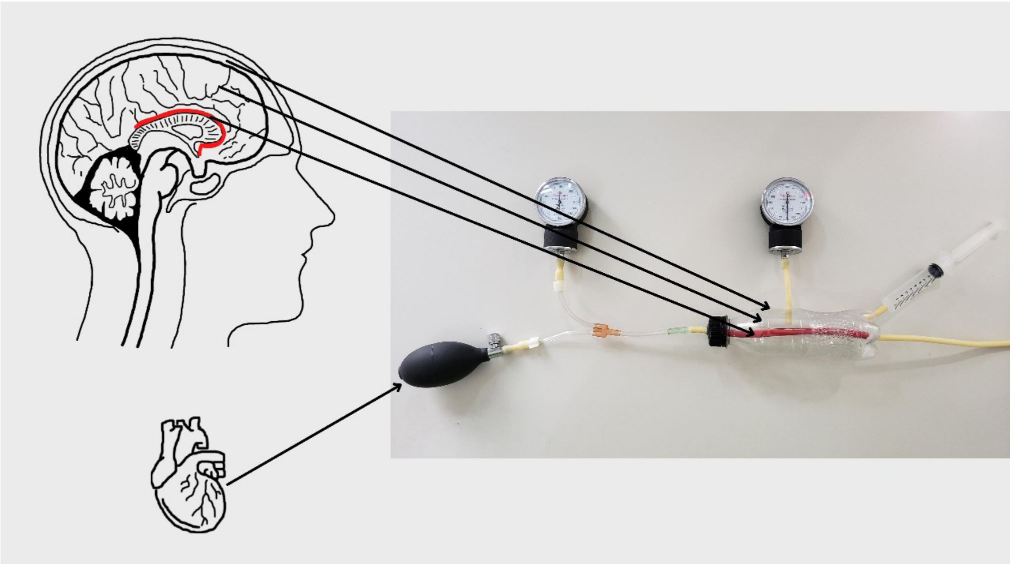

Figure 3 - Analogy between the prototype and anatomical elements of the skull, cerebral vessels. The PET represented the skull. The latex ball simulated a single cerebral blood vessel (perical artery). The latex bulb represented the heart. The space between the latex ball and the PET corresponds to the cerebral compartment, filled by brain mass and CSF.

The compression of the syringe plunger reduced the volume inside the PET and increased the pressure that was recorded in manometer M1 (measured value = 30 mmHg), resulting in vascular collapse (latex ball) and increased resistance to air flow imposed by pressing the bulb connected to the double-lumen line. The increased resistance caused increased pressure inside the ball, recorded in manometer M2 (measured value = 30 mmHg). Additionally, the perception of manual effort to compress the bulb was greater when the pressure inside the PET was increased, representing analogously, an increase in afterload, which corresponds to a greater cardiac effort to pump blood and overcome the resistance imposed on its ejection to maintain adequate CBF.

DISCUSSION

The prototype built in this study allows us to demonstrate in a didactic, intuitive and direct way how the elevation of ICP can result in an impact on blood vessels, raising the CPP, and concomitantly, increasing the work for the heart to maintain the encephalic flow.

The use of didactic prototypes has proven to be a viable teaching strategy, which contributes to make teaching more dynamic and attractive to students, by promoting the dynamization of classes and facilitating the acquisition and assimilation of content[12-14]. Moreover, the use of recyclable material represents an easily accessible, low-cost, and highly applicable alternative[12-14], which contributes to raise awareness about the reuse of materials[12,14]. This easy accessibility of resources for the construction of these teaching prototypes makes it feasible to include these models in basic educational programs, and not only in universities, because it is possible, based on observations, to apply basic science concepts and physical phenomena that can be further developed in a specific way by the student according to his or her vocational orientations.

Practical classes with active teaching strategies are of fundamental importance, since they allow the student to get involved, understand, explore, and apply the concepts taught, allowing the construction of new knowledge from previous concepts[15]. This dynamic facilitates the understanding of the students and fixation of the content [12,15]. In this sense, the prototype developed can make an important contribution as a pedagogical tool within the teaching programs of subjects in the areas of health, in higher education, whose more complex contents require preliminary structuring based on biophysical and physiological mechanisms on the ICP, CPP and CBF.

The model presented provides a didactic and interactive demonstration about the influence of ICP on CPP, including the possibility of analogy with the increased work of the heart muscle (an observation that can be perceived by the effort of the user and generates another point of reflection). Previous studies point to visual teaching strategies as a good learning resource, facilitating the acquisition of knowledge in medical education[16,17]. In this sense, the observation of the prototype functioning, allows the visualization of the cerebral perfusion dynamics and the acquisition of this knowledge through a visual memory, which is important, considering the difficulty of studying these phenomena in vivo, due to the anatomo-physiological complexity of the brain region and its difficult access.

ICH is a very common condition in patients with hypertension and critically ill patients in intensive care units (ICU), and thus, the understanding of the biophysical and physiological basis involved in the increase of ICP is necessary for the correct management of patients in this condition. There are many mechanisms associated to common conditions that may lead to increased ICP, such as cranioencephalic trauma, brain neoplasm, hydrocephalus, meningitis, among others[18,19] and that may, in some way, result in the variation of CPP. The understanding and preliminary reasoning, in isolation, about the concepts and the basic mechanisms involved in the changes of ICP on CPP is important, especially, when multiple variables (that make up the reality of the real physiological context) demand even more abstraction from the scholar. For example, small arteries and arterioles dilate when CPP is reduced, and in contrast, vasoconstriction occurs when CPP is increased, however, this relationship is not linear and it is limited to the capacity of dilation and constriction of the vessels[20]. Therefore, when one of these volumes (blood, CSF or brain mass), alone, is altered, the others must compensate to ensure the ICP, otherwise, the ICH picture is triggered[3].

The use of a didactic pedagogical practice is essential, since the methodology adopted for teaching plays a relevant role in the learning process, which is often equal to the importance of the knowledge itself[21,22]. The teacher plays an important role in the consolidation of the teaching-learning process, as he/she manages the teaching resources and is responsible for stimulating and motivating learning[23-25]. The renewal of didactic techniques has been pointed out as an important tool for maintaining the interest of the student, and facilitating the acquisition or updating of knowledge. In the present study, we show that even with the use of low-cost materials, without elaborate technology, it is possible and feasible to promote a tool that can serve as a guide for an intuitive discussion of complex points that require much abstraction and are difficult to visualize in vivo. So far, we have limited ourselves to didactically illustrate the fundamental biophysical phenomena of ICP over CPP in humans. We suggest that the prototype be tested as a didactic tool and that it may be even improved to demonstrate other variables, such as the flow of fluid through the ball according to the pressure inside the PET.

FINAL CONSIDERATIONS

Our observations lead us to suggest that the prototype has potential as a didactic tool to promote discussions on the fundamental biophysical and physiological principles observed in the generation, maintenance, and variation of ICP, providing a basis for broader discussions on advanced topics surrounding the subject.

Authors contributions: *M.R.M.C, V.T.G.* e *A.C.N.* - conceived, designed and built the prototype, including the construction of the prototype to obtain data; *M.R.M.C* and *A.C.N.* - performed the tests. *M.R.M.C., V.T.G., R.H., C.A.M.J.* and *A.C.N.* - analyzed and interpreted the results; M.R.M.C. - prepared the figures. All authors drafted and revised the manuscript. All authors approved the final version of the manuscript.

Funding: This study was financed with own resources.

Disclosures/Conflicts: The authors declare that they have no competing interests.

Availability of data and materials: Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

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Received: April 11, 2022
Accepted: September 28, 2022