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Noninvasive monitoring of intracranial pressure after cardiac surgery: case report

Monitorização não invasiva da pressão intracraniana após cirurgia cardíaca: relato de caso

Monitorización no invasiva de la presión intracraneal poscirugía cardiaca: reporte de caso

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Claudiane Ayres
ORCID: https://orcid.org/0000-0002-2130-7963
State University of Ponta Grossa, Brazil
E-mail: capfisio-2012@hotmail.com
José Carlos Rebuglio Vellosa
ORCID: https://orcid.org/0000-0003-4747-9197
State University of Ponta Grossa, Brazil
E-mail: vellosajcr@hotmail.com

Abstract
Background: Heart valves are important structures that play an essential role in directing blood flow; changes in the functioning of these structures may require cardiac surgery with cardiopulmonary bypass. The behavior of intracranial pressure (ICP) in patients undergoing this type of surgery is unknown. Objective: aim of this study was to report alterations in the waveform morphology of ICP in a patient submitted to cardiac surgery with cardiopulmonary bypass. Case Description: This report provides data on ICP waveform morphology (P1 and P2 peaks) monitored before, immediately after, and on the 5th day after cardiac surgery. In the preoperative evaluation, the morphology of the patient's ICP waveforms was slightly altered, possibly due to the underlying cardiovascular disease. In the second measurement of the ICP waveforms, performed after surgery, the wave morphology of the ICP was normal. On the 5th PO day, after the patient presented clinical signs of neurological complications, the third ICP measurement was performed, which showed that the morphology of the ICP wave was altered.Conclusions: The use of non-invasive monitoring of ICP is of great importance in patients undergoing cardiac surgery, with the aim of diagnosing, preventing and/or enabling rapid treatment in cases where there is an evolution of more severe neurological complications that may lead to death.
Keywords: Cardiac surgery; Cardiopulmonary bypass; Intracranial pressure; Brain compliance; Noninvasive monitoring.

Resumo
Introdução: As válvulas cardíacas são estruturas importantes que desempenham um papel essencial no direcionamento do fluxo sanguíneo; alterações no funcionamento dessas estruturas podem exigir cirurgia cardíaca com circulação extracorpórea. O comportamento da pressão intracraniana (PIC) em pacientes submetidos a este tipo de cirurgia é desconhecido. Objetivo: o objetivo deste estudo foi relatar alterações na morfologia da forma de onda da PIC em uma paciente submetida à cirurgia cardíaca com circulação extracorpórea. Descrição do caso: Este relatório fornece dados sobre a morfologia da forma de onda da PIC (picos P1 e P2) monitorados antes, imediatamente após e no 5º dia após a cirurgia cardíaca. Na avaliação pré-operatória, a morfologia das curvas da PIC da paciente estava discretamente alterada, possivelmente devido à doença cardiovascular de base. Na segunda medição das formas de onda da PIC, realizada após a cirurgia, a morfologia da onda da PIC estava normal. No 5º PO, após a paciente apresentar sinais clínicos de complicações neurológicas, foi realizada a terceira medida de ICP, que mostrou que a morfologia da onda da PIC estava alterada. Conclusões: A utilização da monitorização não invasiva da PIC é de grande importância em pacientes submetidos à cirurgia cardíaca, com o objetivo de diagnosticar, prevenir e/ou possibilitar o tratamento rápido nos casos em que há evolução de complicações neurológicas mais graves que podem levar ao óbito.
Palavras-chave: Cirurgia cardíaca; Circulação extracorpórea; Pressão intracraniana; Complacência cerebral; Monitoramento não invasive.

Resumen
Introducción: Las válvulas cardíacas son estructuras importantes que juegan un papel esencial en la dirección del flujo sanguíneo; los cambios en el funcionamiento de estas estructuras pueden requerir cirugía cardíaca con circulación extracorpórea. Se desconoce el comportamiento de la presión intracraneal (PIC) en pacientes sometidos a este tipo de cirugía. Objetivo: El objetivo de este estudio fue informar los cambios en la morfología de la forma de onda de la PIC en un paciente sometido a cirugía cardíaca con circulación extracorpórea. Descripción del caso: este informe proporciona datos sobre la morfología de la forma de onda de la PIC (picos P1 y P2) monitorizados antes, inmediatamente después y el quinto día después de la cirugía cardíaca. En la evaluación preoperatoria, la morfología de las curvas de PIC del paciente se encontraba levemente alterada, posiblemente por la enfermedad cardiovascular de

base. En la segunda medición de las formas de onda de la PCI, realizada después de la cirugía, la morfología de la onda de la PIC fue normal. En el 5 PO, luego de que el paciente presentara signos clínicos de complicaciones neurológicas, se realizó la tercera medición de PIC, que mostró que la morfología de la onda de la PIC estaba alterada. Conclusiones: El uso de la monitorización no invasiva de la PIC es de gran importancia en los pacientes sometidos a cirugía cardiaca, con el objetivo de diagnosticar, prevenir y/o posibilitar un tratamiento rápido en los casos en los que exista una evolución de complicaciones neurológicas más graves que puedan conducir a la muerte.
Palabras clave: Cirugía cardiaca; Circulación extracorpórea; Presión intracraneal; Cumplimiento del cerebro; Monitorización no invasiva.

1. Introduction

Heart valves are important structures that play an essential role in directing blood flow between the heart chambers and out of the ventricles (Aires, 2008). During systole, the atrioventricular valves prevent the return of blood from the ventricles to the atrium while during diastole, the semilunar valves prevent the return of blood from the aorta and pulmonary arteries to the ventricles (Gomes, 2005). If there is any change in the functioning of these valves, valve disease occurs, which is classified as valve insufficiency (there is regurgitation of blood due to loss of the ability of the valve leaflets to occlude the passage between chambers) or valve stenosis (the valves do not open properly, causing a reduction in the volume of ejected blood) (Buono, Silingardi, Guerra, 2003). For the treatment of valve diseases, valve repair or valve replacement (VR) surgery is often performed using cardiopulmonary bypass (CPB), which seeks to reconstruct valve function or replace the damaged valve by mechanical or biological prostheses or through the use grafts (Sociedade Brasileira de Cardiologia, 2011). In CPB surgery, a machine provides blood oxygenation and replaces the functions of the heart and lung during cardiac surgery (Silva & Bachur, 2005). The adverse effects of on-pump surgery are mainly caused by the systemic inflammatory response, which occurs as a result of contact of blood with the CPB circuit that leads to the formation of micro-emboli (Hueb & Hueb, 2013). Considering the risk of patients for developing adverse events, cardiovascular and functional monitoring of patients undergoing such procedures is of great importance. The aim of this study was to report alterations in the waveform morphology of intracranial pressure (ICP) in a patient submitted to cardiac surgery with cardiopulmonary bypass.

2. Methodology

This research was approved by the Human Ethics Committee on Research of the State University of Ponta Grossa (UEPG), linked to Plataforma Brasil (Opinion No. 1.752.829). Before the study, all individuals (including the volunteer in this case study) received and signed the informed consent form.

Thus, the present article is a report of a case study that was conducted through observation and evaluation of a patient who underwent VR heart surgery using CPB.

Measurement of ICP was performed about 12 hours before surgery (pre-surgery) in the immediate postoperative (IPO) period and on the 5th postoperative (5th PO) day, approximately 120 hours after surgical intervention. For this purpose, in the preoperative period, the patient was placed on-supine position, lying comfortably with a slight elevation of the head (30º) where she remained still and refrained from talking. The non-invasive ICP monitor sensor was placed in the temporoparietal region of the patient's scalp and secured with an adjustable elastic band, allowing it to be kept as close and firm as possible, preventing the sensor from moving and thus allowing for correct verification of data transmission by the sensor. When attaching the headband with a certain voltage, the sensor pin touches the head and keep the device in the lateral area of the head only, above the ears. The deformations of the skull they can then be perceived as displacements in the sensor pin (Barbosa, 2016; Andrade et. al, 2021).

This non-invasive method allows for the acquisition of ICP through the use of a sensor that acquires data on skull deformation induced by ICP waves without surgery. With the use of the sensor, it is possible to capture the waves and pulses of the ICP that reach the blood, causing expansions and retractions in its volume, being the sensor capable of detecting changes and converting them into numerical values that are impulses and prepared in graphics for interpretation by health professionals (Bollela et al, 2017). This medical device is intended to monitor ICP variations in patients with suspected ICP changes or changes in intracranial compliance. The information is processed and sent in the form of a report with the image waveform and additional information directly on the monitor screen (Andrade et. al, 2021; Bollela et al, 2017).

The morphological analysis of ICP waveforms provides information about intracranial compliance. An increase in ICP waveforms and subsequent decrease in brain compliance lead to a change in the morphology of the ICP pulse. In normal conditions, the ICP waveform morphology exhibits the pattern P1>P2, but when ICP is altered, this changes to P2>P1 (Silva, 2016; Bollela et.al, 2017). Thus, the P2/P1 ratio was defined as the ratio between the amplitude of these two peaks (R=AmpP2/AmpP1), with P2/P1<1.0 being indicative of unchanged ICP. The analysis of ICP morphology and P2/P1 ratio values were performed by Analytics□, which is an analysis system developed by Brain4Care Inc.

In the present study, this system was tested in a patient who developed neurological complications such as decreased level of consciousness, cerebral vasospasm, seizures, hemiparesis, intraparenchymal hematoma, stroke, among others, after cardiac surgery.

We sought to evaluate this patient due to the interest in evaluating whether post-cardiac surgery neurological complications could interfere with ICP, so that we can indicate the use of non-invasive monitoring in patients undergoing such interventions, in order to try to minimize and/ or intervene early to minimize the effects of possible complications.

The aim of the study was to evaluate the waveform morphology of the ICP, which was monitored noninvasively in the pre- and postoperative periods of cardiac surgery, and to identify changes in brain compliance (suggestive of changes in ICP) resulting from the surgery.

3. Results

Case report

A 52-year-old female patient with mitral valve insufficiency underwent surgery for mitral VR (MVR) with CPB. Her immediate response to the intervention was good, as the patient was active, alert, oriented and hemodynamically stable, responding to commands and without signs of mental confusion. But two days after the surgical procedure she developed excessive sleepiness, disorientation, cognitive impairment, and changes in attention level, which are common in neurological disorders.

The first noninvasive evaluation of ICP was performed one day before surgery (pre-surgery) with the patient awake, active, alert, and oriented. After the patient recovered from the anesthesia and was able to breathe without the aid of mechanical ventilation (after removal of the orotracheal tube (OTT)), the second noninvasive ICP evaluation was performed in the IPO. The third evaluation was performed on the 5th PO day, when the patient was drowsy and exhibited signs of a neurological disorder.

Early noninvasive monitoring (as soon as the first signs of neurological changes are detected) helps diagnose complications and allows for prompt treatment in an attempt to prevent development of more severe neurological complications and even death. Thus, an altered ICP waveform morphology would correlate with the signs exhibited by the patient, suggesting a change in brain complacency.

Table 1 summarizes the clinical findings at different times of ICP evaluation, which shows consistency between the clinical signs found by physicians and ICP waveform morphology, as shown in Figures 1, 2, and 3.

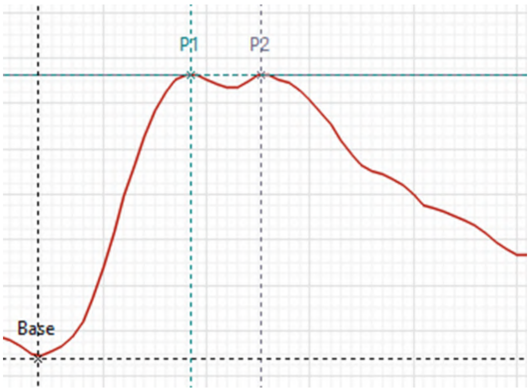
Table 1: Findings during the evaluations.

ASSESSMENT	ICP TRACING MORPHOLOGY	CLINICAL SIGNS
1) Pre-surgery	Slightly altered waveform ICP pattern (suggestive of altered intracranial compliance) P1 and P2 amplitudes are close, but P1>	Patient was awake, active, alert, oriented, and hemodynamically stable
2) Immediate postoperative period	ICP waveforms tracing within the normal range P1>P2	Patient was sleepy but responsive, on spontaneous ventilation, and had good post-surgical evolution
3) 5th postoperative day	Altered waveforms ICP morphology: P2>P1	Patient was sleepy, unresponsive to commands, with signs of a neurological disorder

Source: Authors themselves.

In the preoperative evaluation, the patient's waveforms ICP morphology was slightly altered (probably due to the underlying cardiovascular disease), with P1>P2 (Table 1; Figure 1). At this time, the patient was hemodynamically stable, awake, alert, and oriented.

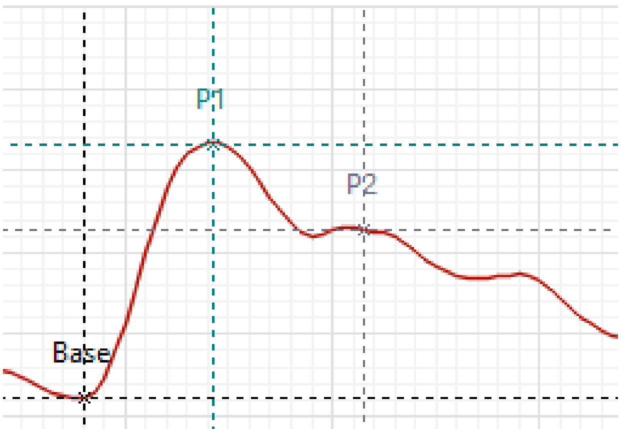
Figure 1: Preoperative waveforms ICP morphology.



Source: Authors themselves (image generated by the system "ICP morphology analyzer"- Braincare Health Technology).

The second waveforms ICP measurement was performed after surgery and removal of the TOT, but was still during the IPO period. The morphology of the ICP pulse was within the normal range, with P1>P2 (Table 1; Figure 2). During this assessment, the patient was drowsy but responsive.

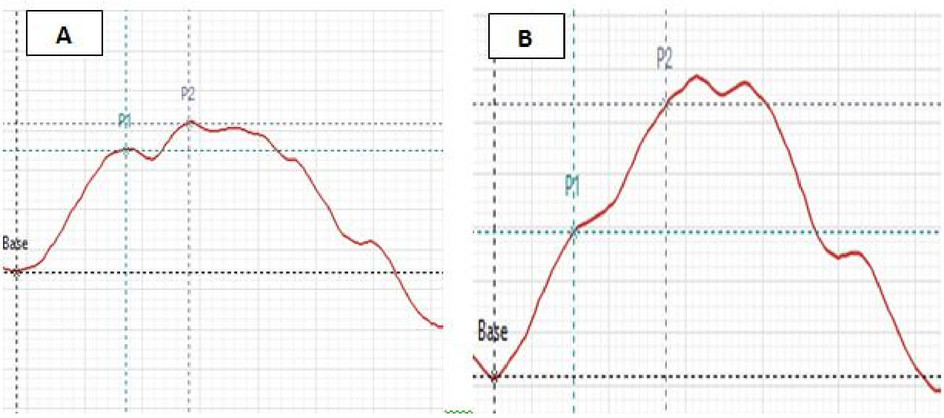
Figure 2: Morphology of the waveforms ICP in the IPO.



Source: Authors themselves (image generated by the system "ICP morphology analyzer" - Braincare Health Technology).

On the 5th PO day, the patient was extremely sleepy, unresponsive, and with clinical signs of neurological complications, but was not given a diagnosis until the moment of monitoring. She underwent a third ICP measurement, which showed that the morphology of the ICP pulse was altered, now being P2>P1 (Figure 3).

Figure 3: Morphology of the waveforms ICP on the 5th PO day.
A: ICP waveform morphology; B: Enlarged graph of ICP waveform morphology



Source: Authors themselves (images generated by the system "ICP morphology analyzer" - Braincare Health Technology).

After investigation by computed tomography (performed on the 6th PO day), ischemic cerebellar stroke associated with compression of the fourth ventricle was diagnosed. Three days after the last evaluation (8th PO day) and after developing several complications, the patient had a cardiopulmonary arrest and died.

4. Discussion

Cardiac surgery is associated with several complications, with the most common being cardiac and pulmonary complications, bleeding, infection of the surgical wound, cerebrovascular diseases, and neurological complications (Beccaria et. al, 2015).

The cardiovascular status may interfere with waveforms ICP and values because under normal conditions, ICP undergoes fluctuations determined by respiratory and cardiac cycles; therefore, it is an important parameter that needs to be evaluated in patients after undergoing cardiac surgery (Carvalho et al, 2006; Westerdahl, 2005).

Carbon dioxide (CO2) has a relaxing effect on the muscles of brain vessels and changes in its levels affect brain vascular resistance, blood flow, and blood volume. Accumulation of CO2 in the interstitial space leads to tissue acidosis, which causes relaxation of the smooth muscles of microcirculation vessels and reduces peripheral vascular resistance. Conversely, when CO2 is eliminated and tissue pH increases, vascular resistance increases and waveforms ICP rises as a consequence (Carlotti et al., 1998). Because waveforms ICP is directly related to cranial volume, its elevation above the normal range may result in reduced blood flow, with consequent ischemia or structural damage due to compression or friction of the brain tissue with the skull, thereby leading to secondary complications (Giugno et. al, 2003).

Non-invasive evaluation of ICP performed on the 5th PO day using a sensor on the temporal region of the head demonstrated a change in the morphology of the ICP pulse (P2>P1), suggesting changes in brain compliance related to a possible increase in ICP.

Some authors report that neurological complications are usually associated with the formation of micro-emboli during the surgical procedure as a result of the systemic inflammatory response caused by contact of blood with the CPB circuit, stating that this has a direct effect on the pathogenesis of neurological abnormalities detected in the postoperative period (Hueb

& Hueb, 2013; Werneck & Loures, 1973).

Artificial oxygenators contribute to the formation of a large number of micro-emboli during the CPB period and, depending on their size, these emboli may be retained in the brain capillaries. Thus, the use of CPB may result in serious neurological complications, such as leukocyte agglutination with deposition in the microcirculation, neurological disorders, cognitive impairment, changes in the level of attention, changes in the sleep-wake cycle, changes in gait, changes in memory, simple disorientation, mild to extreme confusion, and psychomotor agitation (Lelis & Auler Jr, 2004; Barbosa et al., 2010; Torrati & Dantas, 2012). Neurological lesions may also occur due to changes in blood flow, prolonged hypoxia, a systemic inflammatory response, micro-emboli, intracardiac thrombi, and air emboli (Barbosa et al., 2010).

Postoperative neurological dysfunctions compromise the quality of life of the affected patients and can range from transient discomfort to irreversible damage to the central nervous system, such as hemorrhage, brain ischemia, or stroke (Lelis & Auler Jr, 2004; Barbosa et al., 2010; Torrati & Dantas, 2012).

A study involving 320 patients who underwent heart surgery, of which 310 underwent CPB, showed that only 7.8% had postoperative complications. A total of 24 patients had severe neurological complications, of which 10 patients had air embolism, six had cerebral ischemia, two had fat embolism, two had calcium embolism, one had venous hypertension, and three had other complications (Werneck & Loures, 1973).

A study involving 83 patients submitted to cardiac surgery using CPB showed that the percentage of neurosensory alterations characterized by agitation, cognitive deficit, or seizures was 43.2% in the group that had shorter CPB time (up to 85 minutes) and 43.6% in the group with longer CPB time (more than 85 minutes). Thus, they concluded that the frequency of most neurological complications occurring in the IPO period was similar regardless of CPB time (Torrati & Dantas, 2012).

The patient assessed in our study developed neurological dysfunction after undergoing MVR surgery and then died eight days after the surgery. A study that analyzed the medical records of 2648 patients showed that 41% of patients who developed neurological lesions eventually died (Beccaria et. al, 2015).

In another study conducted to investigate the types of complications occurring in the postoperative period (until the 2nd day after surgery) of coronary artery bypass graft (CABG), data were collected from the electronic medical records of 119 individuals. It was found that 28 patients (23.5%) had some type of complication. Six patients (5%) had neurological complications, including stroke, aphasia, behavioral changes, agitation, apathy, diffuse brain damage, and mental confusion (Carvalho et. al, 2006).

The investigation of the medical records of 204 patients undergoing cardiac surgery showed that the prevalence of complications in the IPO was 58%, which were mostly pulmonary complications (31.02%), followed by cardiac (15.78%) and neurological complications (13.9%). The main neurological complications observed were altered level of consciousness or coma; sensory, motor or reflex alterations at any time during the postoperative period; and stroke (Soares et. al, 2011).

Barbosa et al. (2010), in a review article, reported that 51.7% of analyzed papers described the occurrence of neurological complications in procedures that used CPB. In addition, the authors of a retrospective study reviewing the medical records of 493 patients undergoing on-pump CABG reported an age over 70 years and a previous history of stroke, peripheral vascular disease, chronic renal failure, smoking, diabetes mellitus, proximal aortic atherosclerosis, and hypertension as risk factors for stroke, as well as observed a high mortality rate in patients who had stroke as a complication after on-pump CABG surgery (Silva & Bachur, 2005).

The complication that the patient experienced in the present study, which presented after surgical intervention with CPB, was an ischemic cerebellar stroke associated with fourth ventricular compression and increased ICP, confirmed by invasive monitoring through the insertion of an intracerebral catheter connected to a transducer and to a display at the patient's bedside. Neurosurgery involving implantation of an external ventricular drain to normalize ICP was necessary.

Unfortunately, one of the limitations of this study was the non-invasive monitoring of the ICP after the patient's death, due to protocol issues at the Hospital Unit, which prioritizes the preparation and referral of the body to the morgue as soon as possible, in order to enable the funeral service to take the appropriate measures for funeral and burial ceremonies. Such monitoring could elucidate whether after death there would be important changes related to ICP, which could predict worsening of the clinical picture capable of culminating in the death of patients.

5. Conclusion

In view of the possibility of several neurological complications occurring after cardiac surgery, the monitoring of vital signs and cardiovascular and neurological functions is important in following up the clinical course of patients. Thus, the use of noninvasive monitoring of ICP is a tool that will greatly aid in diagnosis, prevention and/or fast treatment of the condition in an attempt to prevent the development of more severe neurological complications and even death. Prospective studies are still needed to clarify the relationship between the complications of cardiac surgery with CPB and changes in brain compliance. Therefore, it is suggested that further studies seek to investigate this relationship.

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