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Aeromedical Transportation in an Area Intensive Care Unit: Experimental Study of Aircraft Pilots Undergoing Non-Invasive in-Flight Intracranial Pressure Measurement

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ABSTRACT

Introduction: In certain emergency situations, a patient admitted to a hospital with fewer resources needs to be transferred quickly to a unit better prepared to deal with them. This is when the aeromedical transport service is needed. For this, the aircraft must be staffed by specialized health professionals and have a variety of resources to provide the best care for the patient.

Objectives: 1) The general objective of this article was to analyze changes in intracranial pressure (ICP) in Brazilian Air Force pilots undergoing a level straight flight. 2) To help collect data for the development of a non-invasive sensor for monitoring ICP in flight. 3). To verify whether the equipment for measuring non-invasive Intracranial Pressure can be used in air ICUs.

Materials and Methods: The work evaluated the presence of morphological changes in non-invasive ICP during level straight flight lasting 30 min among 10 (ten) pilots who volunteered for the collection.

Results: It was observed that the ICP pulse waveform did not change during straight level flight, when compared to normal resting situations of an individual in a collection in a terrestrial environment, demonstrating the reliability of the equipment and the research.

Final considerations: This study has helped to understand not only the need for rapid diagnosis of non-invasive ICP, but also the possible suitability of this equipment in aircraft prepared for rapid diagnosis and tratament.

KEYWORDS: Aeromedical Transportation; Intracranial Pressure; Emergency Aid.

ARTICLE DETAILS

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INTRODUCTION

Aeromedical transport consists of the rescue or removal of seriously ill patients using helicopters or aircraft in places that traditional ambulances cannot easily or quickly reach (primary transport), or even in situations where the patient requires inter-hospital transport that is more suitable by air (secondary transport). It is considered to be a safe form of transportation, and although it has some disadvantages, it is very fast, which provides almost immediate assistance to the injured/patients and can save many lives (GOMES et.al, 2013).

Mandatory training for staff working in the Aeromedical Intensive Care Unit (ICU) includes courses in Aerospace Medicine (since the human body behaves differently depending on the altitude), flight physiology, on-board interventions, general emergencies, among other topics (SCHAPS et.al, 2022).

In addition, all aircraft and flight teams must be approved according to the criteria of the Regional Council of Medicine from Brazil (CRM), Regional Council of Nursing (COREN) and ANS (National Health Agency), as well as ANAC (National Civil Aviation Agency of Brazil) (BEZERRA et.al, 2018).

Every air ICU must have at least one doctor and one nurse trained in air care (ANDREW et.al, 2017).

According to Bezerra et.al (2018), every air ambulance should have the following equipment: Stretcher; multi-parameter monitor (capable of monitoring heart function, oxygen and CO2 saturation, temperature, among other fundamental parameters for maintaining life); defibrillator; portable ventilator; immobilization kit.

According to Dutra et.al (2018), there are several reasons for the need for national or international aeromedical transportation. For Air ICU transportation, the agility and technical competence of the aeromedical transportation company is extremely important. The air ICU must be complete and modern, with state-of-the-art equipment, together with an efficient and prepared medical team.

Transporting patients by air is a very important stage that requires speed and efficiency. Any further delay during this process could jeopardize or even make it impossible to continue living (BROWN et.al, 2022).

Behind this type of transport is a competent and attuned crew that meets certain requirements, and specialized equipment and materials, which make it possible for all transportation to be carried out without any incident (ADCOCK et.al, 2020).

In addition to transporting patients, the air ICU must be able to transport organs. According to Borges et.al (2022), the waiting time to receive an organ is crucial for many patients on the waiting list, and speedy delivery of the organ is essential to ensure its viability.

In these cases, the air ICU is the only form of transportation that can guarantee timely delivery of the organ, reducing the waiting time and increasing the chances of a successful transplant. The air ICU is responsible for transporting the medical team responsible for the transplant, who need to be available to carry out the surgery immediately after the organ arrives (SCUISSIATO et.al, 2012).

Pereira et.al (2021) points out that transporting organs by air ICU requires complex logistics, which involves the rapid and safe transportation of the organ, the medical team responsible for the transplant and the appropriate conditions for transporting the organ.

For this reason, the aircraft used in the air ICU for organ transportation are equipped with advanced organ preservation technology, such as thermal boxes and systems for constantly monitoring the temperature and humidity of the environment. In addition, the team responsible for transportation is trained to deal with emergency situations and to guarantee the safety of the organ throughout the process (TORRES et.al, 2008).

In summary, the air ICU is essential for the transportation of organs for transplant, guaranteeing the speed and safety of organ delivery and increasing the chances of a successful transplant. The complex logistics involved in this type of transportation require a highly qualified team and state-of-the-art equipment, which guarantees the viability of the organ throughout the process (ESSEBAG et.al, 2003).

The sophistication of aeromedical transport depends on the needs and characteristics of each country. One of the main distinctions concerns territorial dimensions, but territorial extension is not the only important factor. Population distribution, the existence of isolated settlements and the high number of road accidents are also important characteristics (HSIA et.al, 2018).

Aircraft have undergone a major transformation, moving from rudimentary equipment to helicopters, jets and airplanes with high-tech equipment, so that they can respond to any type of situation (FIGURE 1).

Figure 1. Aircraft with all the necessary ICU equipment. Source: setetaxiaereo.uti-aerea

INTRACRANIAL PRESSURE

Idiopathic intracranial hypertension is characterized by increased pressure inside the skull (intracranial pressure). It has not yet been determined what triggers the problem. People experience daily or almost daily headaches, sometimes with nausea, blurred or double vision, and noises inside the head (acupheno) (WELLING et.al, 2019).

Intracranial Pressure (ICP) means inside the skull and hypertension means high fluid pressure. A condition of intracranial hypertension means that the pressure of the fluid surrounding the brain (cerebrospinal fluid or CSF) is too high (FENG et.al, 2009).

The skull as a rigid box. After brain injury, the skull can become overloaded with: swollen brain tissue, blood or cerebrospinal fluid. The skull doesn't stretch like the skin to cope with these changes. It can become too full and increase the pressure in the brain tissue. This is called increased intracranial pressure (BEZERRA, et.al, 2018).

According to Welling et.al (2019), ICP is normally less than 10-15 mmHg in adults and intracranial hypertension with potentially deleterious effects is present when the pressure is ≥ 20 mmHg. Occasional and transient elevations in ICP, accompanied by coughing, sneezing or Valsalva manoeuvres, are normally stabilized by homeostatic mechanisms.

In adults, the intracranial compartment is protected by the skull, a rigid structure with a fixed internal volume of 1400 to 1700 ml. Under normal conditions, the intracranial content includes (by volume): Brain parenchyma - 80-85%; Cerebrospinal fluid (CSF) - 5-10%; Blood - 8-12% (CZOSNYKA et.al, 2004).

Dunn et.al (2002) described that pathological volumes, such as lesions with a "mass effect", for example abscesses or hematomas, can be present within the intracranial compartment.

Since the total volume of the intracranial compartment cannot change, an increase in the volume of one of the components, or the presence of a pathological component, needs to be compensated for by the displacement of another structure or the ICP will increase. Therefore, ICP is a function of the volume and compliance of each of the intracranial components. This relationship was recognized more than 150 years ago and is called the Monro-Kellie doctrine (FREEMAN et.al, 2015).

According to Bratton et.al (2007), the volume of the brain parenchyma is relatively constant in adults, although it can be altered by mass effect lesions or cerebral edema. CSF is produced by the choroid plexus at a rate of 20 ml/h (around 500 ml/day). It is normally reabsorbed in the arachnoid granulations by the venous system. Alterations in the regulation of CSF content can occur in ventricular obstructions or venous congestion (e.g. sagittal sinus thrombosis). An increase in CSF production is a rare event, but can occur in cases of choroid plexus papillomas. Cerebral blood flow (CBF) determines the volume of blood in the intracranial space. CBF increases with hypoxia and hypercapnia. Autoregulation of CBF may be lost in brain injuries and can result in severe brain swelling, especially in children. The interrelationship between changes in the volume of intracranial contents and variations in ICP define the compliance of the intracranial compartment.

CEREBRAL BLOOD FLOW

Hawryluk et.al (2022) describes that with a significant increase in ICP, additional brain damage can result from compression of the brainstem or reduced cerebral blood flow (CBF).

CBF is a function of the pressure difference across the cerebral circulation divided by the cerebrovascular resistance, according to Ohm's law: CBF = (CAP - PVJ) CVR where, CAP is carotid arterial pressure, PVJ is jugular venous pressure and CVR is cerebral vascular resistance (HAWRYLUK et.al, 2022).

Bothwell et.al (2019) cites that cerebral perfusion pressure (CPP) can be used as clinical information on cerebral perfusion. CPP is defined as mean arterial pressure (MAP) minus intracranial pressure (ICP): CPP = MAP – ICP.

CEREBRAL PERFUSION PRESSURE (CPP)

Conditions associated with elevated ICP may be associated with reduced CPP. This can result in focal or global cerebral ischemia. On the other hand, excessive elevation of CPP can lead to hypertensive encephalopathy and cerebral edema, due to a breakdown in cerebral autoregulation, especially if CPP rises above 120-140 mmHg. Higher levels of CPP can be tolerated in patients with chronic hypertension. Focal or global reductions in CBF are responsible for many of the clinical manifestations of high ICP (EVENSEN et.al, 2020).

CLINICAL MANIFESTATIONS

According to Evensen et al (2020), the clinical manifestations of ICH can be divided into general, focal and herniation syndromes. General symptoms of ICH include headache, probably mediated by painful trigeminal fibers in the dura mater and blood vessels, vomiting and a global decrease in the level of consciousness due to pressure on the mesencephalic reticular substance. Signs of ICH include papilledema (due to decreased axonal transport of the optic nerve and venous congestion), cranial nerve palsies (mainly of the sixth nerve), and Cushing's triad (hypertension, bradycardia and respiratory depression).

The presence of this triad requires urgent intervention because it usually means severe compression of the brainstem (EVENSEN et.al, 2020; HAWRYLUK et.al, 2022).

MEASURING NON-INVASIVE INTRACRANIAL PRESSURE

The great difficulty for researchers is to carry out an experiment in flight, with the aim of measuring non-invasive intracranial pressure in flight, so that this equipment can be used in air ICUs (BEZERRA et.al, 2018).

The best way to control intracranial hypertension is to resolve the immediate cause of high ICP. Regardless of the cause, treatment should be started as soon as possible and is based on the principles of resuscitation, rapid and intensive control of hypoxemia, hypoventilation and hypotension, reduction of intracranial content and constant reassessment (EVENSEN et.al, 2020; HAWRYLUK et.al, 2022).

If the patient is showing signs of decompensation and herniation, drug treatment should take place if necessary, hyperventilation; establish a radiological diagnosis and treat the immediate cause intensively (HAWRYLUK et.al, 2022).

OBJECTIVES

The general objective of this article was to analyze the change in intracranial pressure non-invasively in Brazilian Air Force pilots undergoing a level straight flight.

Specific Objectives

I. To assess intracranial pressure variations in pilots during flight in a Brazilian Air Force aircraft (T-25).
II. To help collect data for the development of a non-invasive sensor for monitoring ICP in flight.
III. To check whether the equipment for measuring non-invasive Intracranial Pressure can be used in air ICUs.

MATERIALS AND METHODS

(i) Finalized collection of ICHP from 10 (ten) military personnel in the T-25 aircraft. Analysis of intracranial pressure variation during the experiment.

Temporal analysis of the intracranial pressure curve was carried out using graphs showing the variation in ICP throughout the procedure, making it possible to check whether there was an increase or decrease in intracranial pressure.

Analysis of the morphology of the intracranial pressure pulses.

The data obtained during the maneuvers with the volunteers was used to analyze the morphology of each intracranial pressure pulse. ICP has a characteristic morphology. The study assessed the presence of morphological alterations during normal situations during level straight flight lasting 30 min.

STATISTICAL ANALYSIS

Descriptive statistics were carried out for each sample, considering absolute (n) and relative (%) frequencies. The mean, median, lower and upper quartiles, maximum and minimum of the following variables were calculated: weight; height; age and metrics related to ICP.

The data was analyzed using parametric or non-parametric tests depending on the distribution found. In the presence of a normal distribution of residuals, the analysis of variance (ANOVA) technique was applied in order to assess whether there was a significant difference when considering ICP metrics. The significance level adopted was 0.05 (α = 5%) and descriptive levels (p) below this value were considered significant. The data obtained during the experiments was recorded on an SD card in the intracranial pressure monitor itself and was then used for mathematical analysis using Matlab, Origin and ICM+ software.

VOLUNTEERS

The volunteers for this study consisted of 10 (ten) Flying Officers from the Brazilian Air Force (FAB) with extensive flying experience.

Inclusion/exclusion criteria;

Pilots who had passed the Conditioning Assessment Test and Technical Instructions for Aeronautical Health Inspections.

The following were considered;

- fit for this study airmen who passed the Physical Conditioning Assessment Test (TACF) regulated by the Aeronautics Command Systemic Standard (NSCA) 54-1 (2004), carried out every semester at the Air Force Academy (AFA).

- fit airmen who underwent an annual examination at the Aerospace Medicine Centre (CEMAL), an Aeronautical Health Organization (OSA) designated by ANAC, through an agreement with the Aeronautical Command (COMAER), and obtained the Certificate of Physical Capacity (CCF) during the inspections.

- military personnel who have passed the periodic medical assessment of aircrew established by the - Technical Instructions for Air Force Health Inspections. ICA 160.1 of the Aeronautics Command, carried out every six months in the FAB.

- Unfit to take part in this study: military personnel who have failed any of the reports relating to the Conditioning Assessment Test and medical assessment, in accordance with the Technical Instructions for Air Force Health Inspections.

ETHICAL ASPECTS

Ethical considerations were based on scientific purposes, with confidentiality of the pilots' identity, free from coercion or conflict of interest on the part of the institution or people involved in the project. The samples were taken in accordance with the technical protocols for pilot and aircraft safety. The volunteers were informed beforehand and the ICH measurement was analyzed with their express consent on a specific form (Informed Consent Form - ICF), in accordance with Resolution 196/96 of the CEP. Opinion number: 1.015.756.

Date of Rapporteur: 14/04/2019, CAAE: 40667114.7.0000.5504.

This study used intracranial pressure to understand the effects of circulation during flight in order to study cerebral hemodynamics and brain function.

The researcher PhD. Thiago Augusto Rochetti Bezerra, coordinator of this project, received financial support from the São Paulo Research Foundation (FAPESP - Process No. 2014 / 21803-7).

We used the Braincare BcMM 2000 2.0 Monitor (Braincare Health Technology) (FIGURE 2) to monitor and record the data using a sampling rate of 200Hz.

The intracranial pressure sensor used was the non-invasive sensor developed by Braincare Health Technology (FIGURE 2).

Figure 2. Braincare BcMM 2000 2.0 monitor Source: (Braincare Health Technology). Source: brain4.care

The product is a sophisticated piece of equipment, individually calibrated and tested. The Quality Certification Seal is a sign that the product purchased has passed all the tests provided for in its quality control plan.

The INMETRO seal, as well as the ANVISA registration identification, indicates that it complies with the regulations and standards applicable in Brazil.

The purpose of the BcMM 2000 is to monitor patients' vital parameters with alarm, recording and communication functions with other equipment and systems. The parameters covered by the monitor are Intracranial pressure by non-invasive, minimally invasive and invasive means, invasive and non-invasive blood pressure, oxygen saturation, 2 temperature channels and electrocardiogram.

Data Collection

The volunteers' intracranial pressure was monitored next to the occipital bone using the Braincare non-invasive intracranial pressure sensor attached to the pilots' helmets (FIGURE 3). The BcMM 2000 ICP measuring device was attached to a bag and fixed to the pilot's chest muscles (FIGURE 4).

Figure 3. Sensor attached to the pilot's helmet and head. Source: Authors.

Figure 4. Positioning of the BcMM 2000 equipment inside the T-25 aircraft. Source: Authors.

The duration of the monitoring during the flight was 30 minutes, carried out in the Neiva T-25 Universal aircraft (FIGURE 5).

Figure 5. Neiva T-25 Universal aircraft. Source: Brazilian Air Force.

SD card

The data acquired during patient monitoring was recorded on an SD card, which can be read on any computer (FIGURE 6).

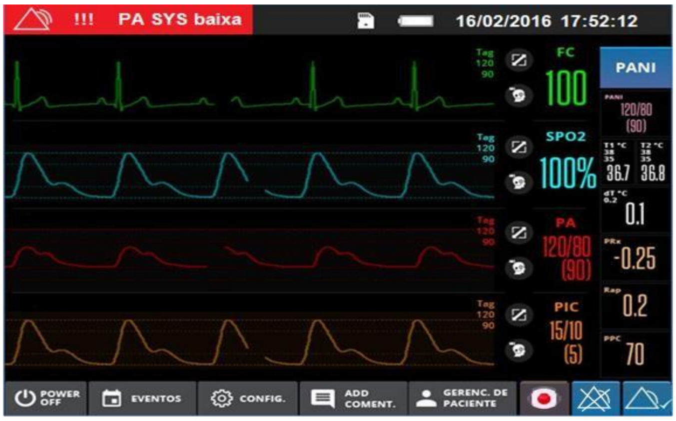

Figure 6. BcMM 2000 multiparameter sensor panel. Source: brain4.care

RESULTS

The study volunteers had the following characteristics (mean±SEM): age 21.3±0.27 years, weight 72.8±1.75 kg and height 1.78±0.01m.

It was observed that the ICP pulse waveform did not change during level straight flight, when compared to normal resting situations of an individual in a collection in a terrestrial environment.

Figure 7 shows the ICP pulse waveform of 10 pilots. No differences were found in the ICP during all the flights used in this study.

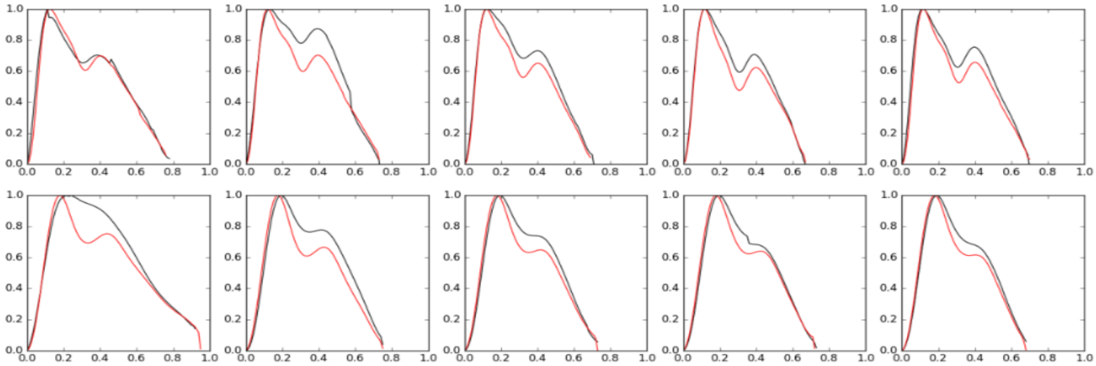

Figure 7. ICP morphology recorded in flight by each pilot. Source: Authors.

Analysis of the normalized time to peak and pulse area found no statistical difference. This analysis indicates that the normalized pulse of the ICP in both pilots remained unchanged during the flight (FIGURE 8).

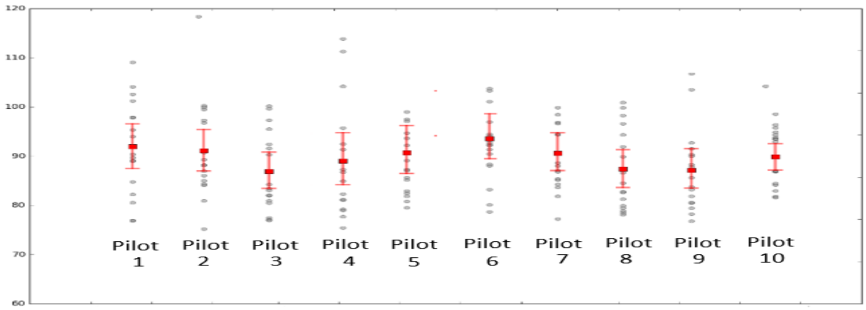

Figure 8. PCI pulse distribution of each pilot during level straight flight. Source: Authors.

The normalized time for the pulse to reach its maximum can be seen for each sample. The red bar represents non-parametric confidence intervals (a=0.05, N=1000).

The peak-to-peak range of the ICP waveform. It was observed that the ICP values did not change during the level straight flight, demonstrating the reliability of the sample.

The cable connecting the sensor to the monitor was shielded to prevent it from being influenced by the instruments on the T-25 aircraft. All safety regulations were complied with in order to carry out the study.

The current study demonstrated the feasibility of monitoring clinical parameters in flight.

DISCUSSION

According to Chesnut et al (2020), the assessment and support of ventilation, oxygenation, blood pressure and tissue perfusion are fundamental and applicable to all patients without distinction.

The aim of monitoring ICP and treating ICH is to maintain ICP below 20 mmHg and CPP above 60 mmHg. Any intervention should only be instituted after ICP remains above 20 mmHg for more than 5 to 10 minutes, since transient elevations in ICP can occur with coughing, movement, periods of aspiration and asynchrony with the ventilator (KOCHANEK et.al, 2022).

The identification of pathological waves, with rapid and repetitive ICP elevations, also indicates the need for intervention.

As mentioned above, the best treatment for elevated ICP is to treat the immediate underlying cause. If this is not possible or has not been sufficient, a series of steps should be initiated to reduce ICP and minimize further brain damage. In all cases, the doctor should keep in mind the items of resuscitation, intracranial volume reduction and frequent reassessment. In this case, the air ICU can be essential for the rapid rescue and adequate treatment of the patient.

FINAL CONSIDERATIONS

The new equipment for measuring Intracranial Pressure non-invasively can be used to monitor vital parameters in clinics, outpatient clinics, intensive care units, surgical centers and transport within hospitals, air and ground transport.

This study helped to understand not only the need for rapid diagnosis of non-invasive ICP, but also the possible suitability of this equipment in aircraft prepared for rapid diagnosis and treatment.

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