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Evaluation of intraosseous pressure in a hypovolemic animal model

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ARTICLE INFO

Article history:
Received 15 May 2014
Received in revised form
27 June 2014
Accepted 1 July 2014
Available online 7 July 2014

Keywords:
Intraosseous
Central venous catheter
Blood pressure
Hemorrhage
Shock

ABSTRACT

Background: In emergent situations, access to the vascular bed is frequently required for fluid and medication administration. Central venous catheter placement is associated with risk and may slow resuscitation in the unstable patient. The purpose of this study was to determine whether intraosseous pressure (IOP) could be consistently recorded and how similar this pressure was to central venous and arterial pressure in a porcine hemorrhagic shock model.

Materials and methods: After sedation, eight female swine had catheters placed in the femoral vein, aorta via femoral artery, and superior vena cava. IOP lines were placed in the proximal humerus, distal femur, and proximal tibia. Pressure readings were recorded continuously through the five stages of progressive hypovolemia. Pressure data were descriptively summarized, with the percent of change of IOP at each stage compared with arterial pressure using a multilevel mixed effects linear model with log transformation.

Results: The IOP baseline values were between 16 and 18 mm Hg, approximately 22% of baseline arterial pressure. The intraosseous (IO) waveform mostly closely resembled the arterial pressure waveform, including the presence of a dichroitic notch. Pressure variations caused by ventilation (respiratory variability) were also identified in all the tracings. The rate of pressure change in the humeral IO most closely matched the change in arterial pressure rate. IO blood gas analysis showed gas composition to most closely match venous blood.

Conclusions: IOP was reliably obtained in this porcine model and suggests potential for clinical application in humans.

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0022-4804/$ – see front matter © 2015 Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.jss.2014.07.007

1. Introduction

In emergent situations, access to the vascular bed is frequently required for fluid and medication administration. To achieve this, as well as monitor hemodynamics, emergency and critical care physicians frequently use central venous catheters (CVC). There are an estimated 5 million CVC insertions per year in the United States [1]. Historic data demonstrate morbidity associated with CVC placement including mechanical complications due to misplacement [2–4], infection in 5%–26% of patients in a recent review [3,5–7], and thrombotic complications (2%–26%) [3]. Mortality is also a significant concern, with a wide range of estimates for attributable mortality related to catheter complications [8–11]. The average cost of care for a patient with a central line associated bloodstream infection has been estimated at $45,000, with an estimated annual cost to the United States healthcare system as high as $2.3 billion [8]. Although reduction of central line-associated bloodstream infections has been achieved through focused attention and implementation of best practices, it remains a significant issue for critically ill and injured patients [12].

Due to a preference for venous access and lack of knowledge about the intraosseous (IO) space, IO access has been used sparingly by healthcare professionals and rarely in adults. However, with the development of new IO placement systems, the technique has gained utility as a rapid fluid and/or medication administration site. For this reason, the American Heart Association has endorsed IO access in patients in cardiac arrest [13]. This technique provides a secure access port within the IO matrix at the ends of long bones. Unlike compliant veins, the intramedullary space is rigid and does not collapse in shock, and prompt delivery of life-saving fluids or medications to the central circulation is possible. IO ports have been placed successfully and quickly in a variety of care delivery scenarios [14,15] In addition, blood withdrawn from IO ports can be sent for analysis by the clinical laboratory [16,17]. A low complication rate between 1 and 3% has been reported with IO insertion and infusion, with compartment syndrome and osteomyelitis rates reported at <1% [14,18].

An important feature of placing a central venous line has been the ability to monitor central venous pressure (CVP) as an estimate of intravascular volume. A recent meta-analysis found that static CVP values can be a poor guide for fluid resuscitation therapy [19]. A subsequent review concurred with this analysis and recommended that practitioners avoid CVP monitoring for intravascular volume assessment [20]. Variation in arterial pressure waveform tracings, due to respiration, has been recommended as an accurate indicator of fluid volume responsiveness [21,22].

Use of IO technology could be further expanded in the initial stages of resuscitation, if this form of venous access could also be used to monitor IO space pressures. There has been little research to date evaluating intraosseous pressure (IOP) and its ability to serve as a consistent and reliable method for approximating traditional measures of CVP. In this study, we aimed to evaluate whether reliable IO space pressures could be detected from three different IO spaces in a porcine hemorrhagic shock model. Second, we compared the characteristics of the IO pressure waveforms during baseline and evolving hypovolemic conditions with the CVP and arterial waveforms, including an evaluation of the presence of respiratory variability in the IO pressure waveform as a potential indicator of fluid volume status. Third, we compared the rate of pressure change from the IO spaces with the arterial pressure as hypovolemia developed. And finally, we evaluated blood gas samples from the IO space to evaluate whether blood gas composition is comparable with venous or arterial samples.

2. Materials and methods

2.1. Study design

This study was a prospective interventional animal study using a porcine hemorrhagic shock protocol to investigate IOP characteristics. This protocol was approved by the HealthPartners Animal Care and Use Committee (St. Paul, MN).

2.2. Study setting and population

This study was conducted at an Association for Assessment and Accreditation of Laboratory Animal Care International-accredited animal facility using eight female juvenile healthy Yorkshire pigs (43.1 ± 6.0 kg). Female animals were selected for this protocol due to availability with our local animal supplier.

2.3. Study preparations

All animals were premedicated with intramuscular telazol and/or xylazine (2.2 and 6.6 mg/kg, respectively), and after tracheotomy and intubation, received a continuous flow (0.08–2.0 L/min) of isoflurane-50% nitrous oxide inhalational mixture throughout the study. Ventilation was maintained at 10 mL/kg, f = 15/min, I:E:1:2, FiO_2 = 0.5, and positive end expiratory pressure = 5 cm H_2O. Preparation also included placement of catheters in the femoral vein, aorta via femoral artery, and superior vena cava. IOP lines were placed in the proximal humerus, distal femur, and proximal tibia accessed via standardized technique using a 45 mm, 15-gauge EZ-IO IO needle set (Vidacare LLC; Shavano Park, TX). The technique included identifying the cancellous bone at the end of the humerus, femur, and tibia and using a drill system to insert the stylet and catheter through the skin and cortical bone. After removing the stylet from the catheter, all catheters were aspirated for blood to confirm placement followed by a 10-mL rapid saline flush. Vascular pressure monitoring lines were connected to the arterial, CVP, humerus, femur, and tibia access ports. All pressures were calibrated and continuously monitored by pressure monitoring transducers throughout the study period.

2.4. Hemorrhage protocol

Under baseline conditions, all pressures and their respective tracings, heart rate and cardiac output were recorded. Total porcine intravascular fluid volume was estimated at 65 mL/kg.