Methods for the Evaluation of Right Ventricular Volume Using Ultrasound on a Catheter, in Intensive Care Unit

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ABSTRACT

Hemodynamic monitoring is the main component in intensive care unit (ICU). Patients in ICU are under hemodynamic instability and multi-organ failure for some hours or even some days. Volume–pressure relation constitutes the most reliable method for the estimation of central hemodynamic state and ventricular function. Therefore, the evaluation of intracardiac volume and pressure is necessary. However no available method exists for clinical use that measures the volume of the right ventricular cavity continuously in real time. This paper discusses the methods could be used in measuring the right ventricular volume in the context of an efficient cardiac function evaluation of critical ill patients in ICU, using miniatuirised ultrasound on the tip of a Pulmonary Artery Catheter (PAC), which is anyway used on that purpose but evaluates only pressure.

Keywords: Critical Illness, Hemodynamics, Miniaturized Ultrasound, Pulmonary Artery Catheter, Right Ventricle

INTRODUCTION

Scientific community considers that hemodynamic monitoring is a central component of intensive care (Pinsky & Rayen, 2005). Advanced hemodynamic monitoring is an important part of treatment in clinical situations where aggressive, yet guided hemodynamic interventions are required in order to stabilize the patient and optimize outcome. Cardiac Output (CO) and other hemodynamic parameters play an important role in differential diagnosis, establishing the right treatment plan and monitoring and refining it in real-time. Hemodynamic monitoring is the expert collection and analysis of qualitative and quantitative data of cardiopulmonary function. This monitoring includes clinical observation, the use of electri-
cal, photometric, pressure transducing equipment, as well as the application of a number of intravascular catheters. Fluid-filled monitoring systems attach to intravascular catheters and are used for continuous invasive measurement of arterial and cardiac pressures. Periodic measurement of other pressure/flow and gas exchange parameters may also be performed (National Institutes of Health, http://www.cc.nih.gov). Patterns of hemodynamic variables often suggest cardiogenic, hypovolemic, obstructive, or distributive (septic) etiologies to cardiovascular insufficiency, thus defining the specific treatments required.

Current clinical practice guidelines, based on recent clinical trials that failed to demonstrate a beneficial long-term effect of its use on patients’ outcome, recommend the use of Pulmonary Artery Catheter (PAC or Swan – Ganz catheter) only in certain conditions, such as the differential diagnosis between a cardiogenic and a non-cardiogenic pathophysiology in critically ill patients or the evaluation of hemodynamically unstable patients not responding to the applied therapy (Dickstein, 2008). Any delay to obtain the proper treatment for the critically ill patients, might be fatal. To prevent a possible episode, the prognosis is necessary and important with regard to sudden changes in values of right ventricular volumes which signify an oncoming acute pulmonary embolism or ischemic episode (Vonk Noordegraaf & Gallie, 2011). The three most important factors for hemodynamic evaluation are: preload, afterload and contractility. Right ventricular end-diastolic volume (RVEDV) is the best clinical estimate of right ventricular preload and right ventricular end-systolic volume (RVESV) may be used to estimate RV function (Siniscalchi, 2005). In addition the ejection fraction, \( EF = \frac{EDV - ESV}{EDV} \) is an important index of cardiac performance. EDV is the end diastolic volume and ESV is the end systolic volume. Thus, the calculation of RVEDV and RVESV are of great interest to the clinician.

The PAC is a catheter with length usually at 110cm and external diameter of 7French (or 2.33mm). In order to access the right heart it enters from a large vein which often is the internal jugular or the subclavian vein and though the superior vena cava enters the right atrium as shown in Figure 1. Through the tricuspid valve is inserted to the right ventricle cavity and then curves in order to enter through the pulmonary valve to the pulmonary artery (Headley, 1989).

The curvature of the catheter in the right ventricle chamber has the form of an arc of a circle and could be considered to be the same in any heart as the location and the distance between the valves is approximately unchanged. Therefore, as a result from the above, if a number of ultrasonic sensors are mounted on the catheter surface with certain geometry, the angle of ultrasound beam from the sensor to the ventricular wall will be constant.

Pulmonary artery catheterization has been used for monitoring the circulation, for measurement of intracardiac pressures and to estimate preload and afterload. However, this technique may not accurately reflect the circulation and simultaneous measurement of volumes would improve patient treatment (Kuehne, 2004). Although, measurement of cardiac volumes especially of the right ventricle is difficult in everyday clinical practice, we argue that the development of a system which will enable prognosis and the effective management of hemodynamic status of critically ill patients and especially those with severe heart failure, will improve significantly the quality of healthcare provided, and will constitute a valuable asset in the hands of the medical personnel.

Even if some of these parameters may be estimated by non-invasive techniques, PAC indications still include patients severely ill in the ICU who present with severe circulatory shock, right ventricular failure, acute respiratory failure due to pulmonary edema not responding to treatment, or require complex fluid management (Vincent, 2012). Furthermore, according to the recently published guidelines for the
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