Focused Critical Care Ultrasound Study (FOCCUS)

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Over the last decade, there have been significant developments in bedside echocardiography in the intensive care unit (ICU), the operating room (OR), the non-cardiac setting or the recovery room for hemodynamically unstable patients and patients with contraindications to transesophageal echocardiography (TEE). An approach combining both physical examination and bedside echography has improved the clinical diagnosis and management of acutely ill patients. Such point-of-care echographic examinations are usually "directed" or "focused" toward a specific clinical question and are significantly shorter in duration (less than six minutes in some studies) than conventional echocardiography.[1,2] The goal of such an exam is not to perform a complete, comprehensive study, but rather to further enhance and extend the physical examination.

Transthoracic echocardiography (TTE) is non-invasive and more readily available than TEE and should, therefore, be the modality of choice to perform a goal-directed echocardiographic or echographic examination. [3] So far, it has not been widely used in the ICU and the OR because only a few intensivists and anesthesiologists are TTE-trained. [4] Nonetheless, over the last few years, bedside echocardiography has been increasingly performed by non-cardiologists, intensivists and anesthesiologists to provide diagnostic information not assessable by physical examination alone.[5-73] The TTE exam is called focused, goal-directed TTE, called FOCUS (FOcused Cardiac Ultrasound Study) or FOCCUS (FOcused Critical Care Ultrasound Study), is defined as a TTE performed with specific, limited objectives.[10] The FOCUS objectives include the assessment of left ventricular (LV) function, right ventricular (RV) function, the assessment of the pericardial space for effusion and tamponade, and the assessment of volume status. Three views are used to evaluate cardiac function (Figure 1).

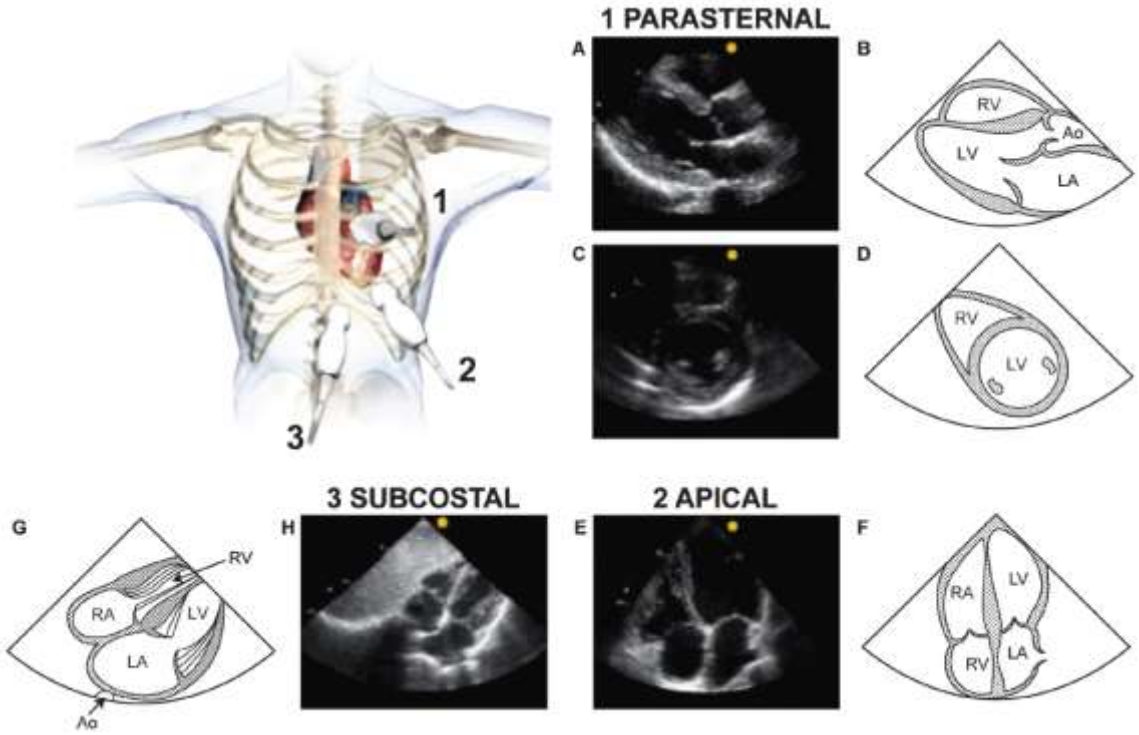

Figure 1 Basic FOCUS echocardiographic views. 1. Parasternal long-axis (A,B) and parasternal short-axis (C,D) views are shown. 2. Apical four-chamber view (E,F) and (3) Subcostal view (G,H) are shown. Abbreviations: Ao, aorta; LA, left atrium; FOCUS, focused cardiac ultrasound study; LV, left ventricle; RA, right atrium; RV, right ventricle. Source: Adapted from the FOCUS pocket guide, with permission from ICCU Imaging Inc. (From Denault A, Couture P, Vegas A, Buithieu J, Tardif JC. TEE multimedia manual 2nd edition.)

Additional FOCCUS objectives include the assessment of lung pathology[8], abdominal fluid, vessels assessment, etc. Competency will eventually have to be established following predetermined levels of training (e.g., levels 1 to 4). Some training guidelines have already been proposed,[9-11] including a consensus between the American College of Chest Physicians and the Société de Réanimation de Langue Française.[12] In order to use this technique a pathophysiological approach that combines clinical, hemodynamic and echographic evaluation has been proposed [13]. It integrated oxygen transport/consumption, pressure-volume relationships and the concept of venous return.

Mechanism of hemodynamic instability

The various components of hemodynamic instability can be explained using the classical concept of venous return as described by Guyton. [14] In simple terms, venous return (VR) is determined by a pressure gradient. This gradient corresponds to the difference between the mean systemic venous pressure (Pms) in the periphery and the right atrial pressure (Pra). This pressure gradient difference is divided by the resistance to venous return (Rvr).

$$VR = \frac{\mathbf{Pms - Pra}}{\mathbf{Rvr}}$$ (Equation 1)

Therefore venous return and, consequently, cardiac output, will be reduced if: 1) the right atrial pressure is elevated, 2) the mean systemic pressure is low, and/or 3) the resistance to venous return is increased. There are several ways to illustrate this relationship. The classical approach to describe venous return and cardiac output is illustrated in Figure 1. [15]. The use of the pressure-volume relationship is used to describe a single cardiac cycle (Figure 2).

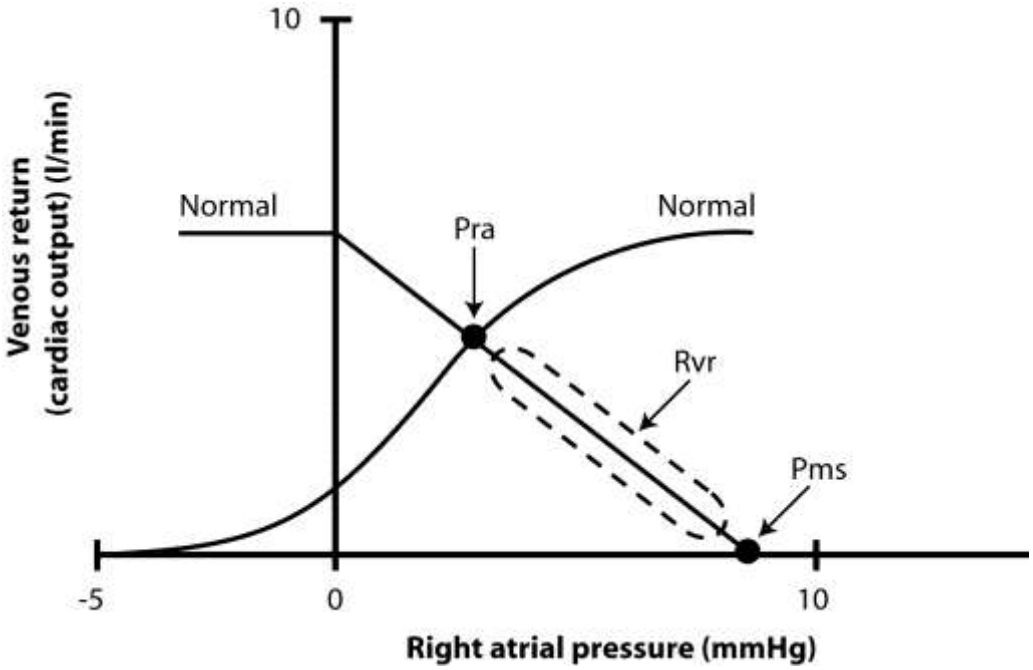

Figure 1 Venous return and cardiac output

The venous return and cardiac output (*y* axis) and its relation with right atrial pressure (*x* axis) is shown. The intersection of both curves will correspond to the right atrial pressure (Pra) at which, in a steady state, an individual will have an unique venous return and cardiac output. The mean systemic pressure (Pms) corresponds to the point where the venous return = 0. The venous return curve is linked to the resistance to venous return (Rvr) (dotted lines) (Adapted from Jacobsohn [15]).

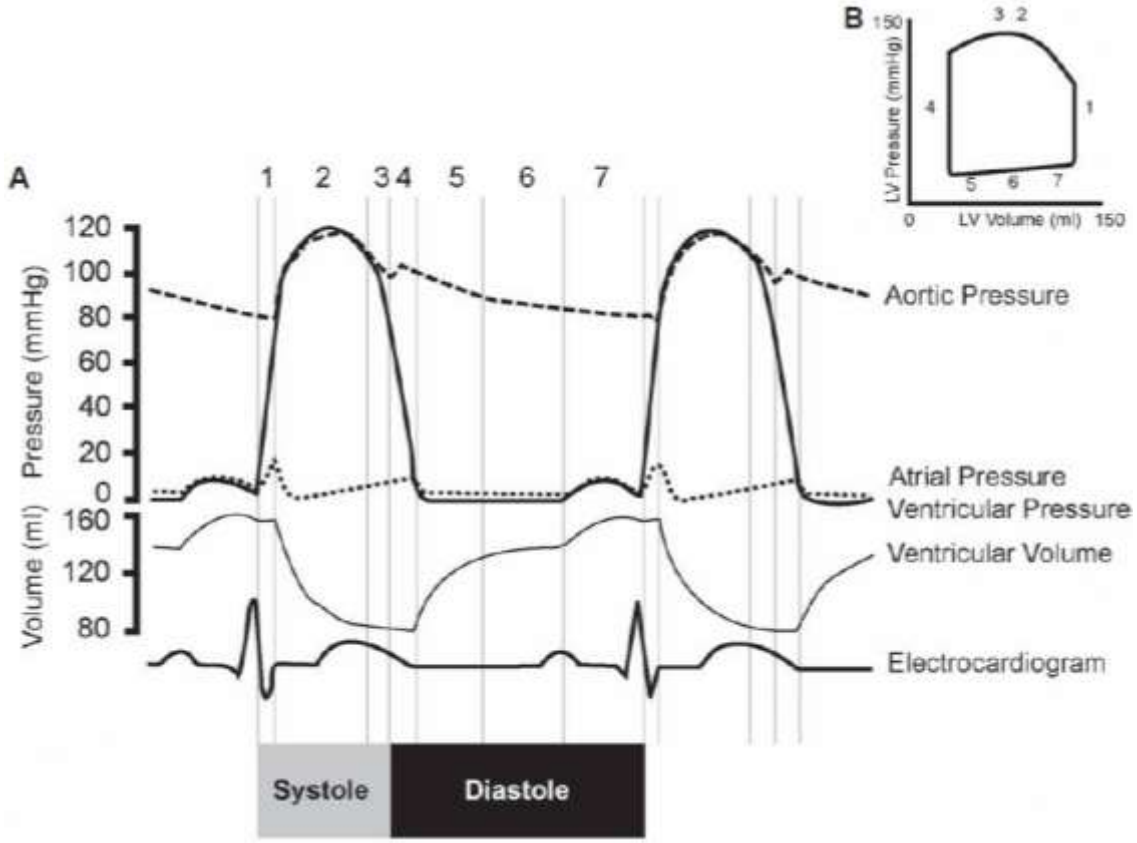

Figure 2 Pressure and volume during a cardiac cycle
(A) Changes in aortic, atrial, ventricular pressure, and ventricular volume in relation to the electrocardiogram. Left ventricular (LV) pressure and volume over time during a cardiac cycle is characterized by seven time-related events. Isovolumic contraction [1] is followed by early [2] and late [3] ejection. Diastole starts with isovolumic relaxation, [4] followed by the early filling phase after the opening of the mitral valve, [5] diastasis, [6] and atrial contraction. [7] (B) Corresponding LV pressure-volume relationship during one cardiac cycle (With permission of Denault *et al.* [16]).

The pressure-volume relationship is typically described for the left ventricle but has also been used to evaluate right ventricular function. [17] The major difference between both ventricles is the reduced pressure in the right compared to the left ventricle. [18] In order to integrate the pressure-volume relationship to the venous return concept, we used a simplified alternative approach illustrated in figure 3. [19]

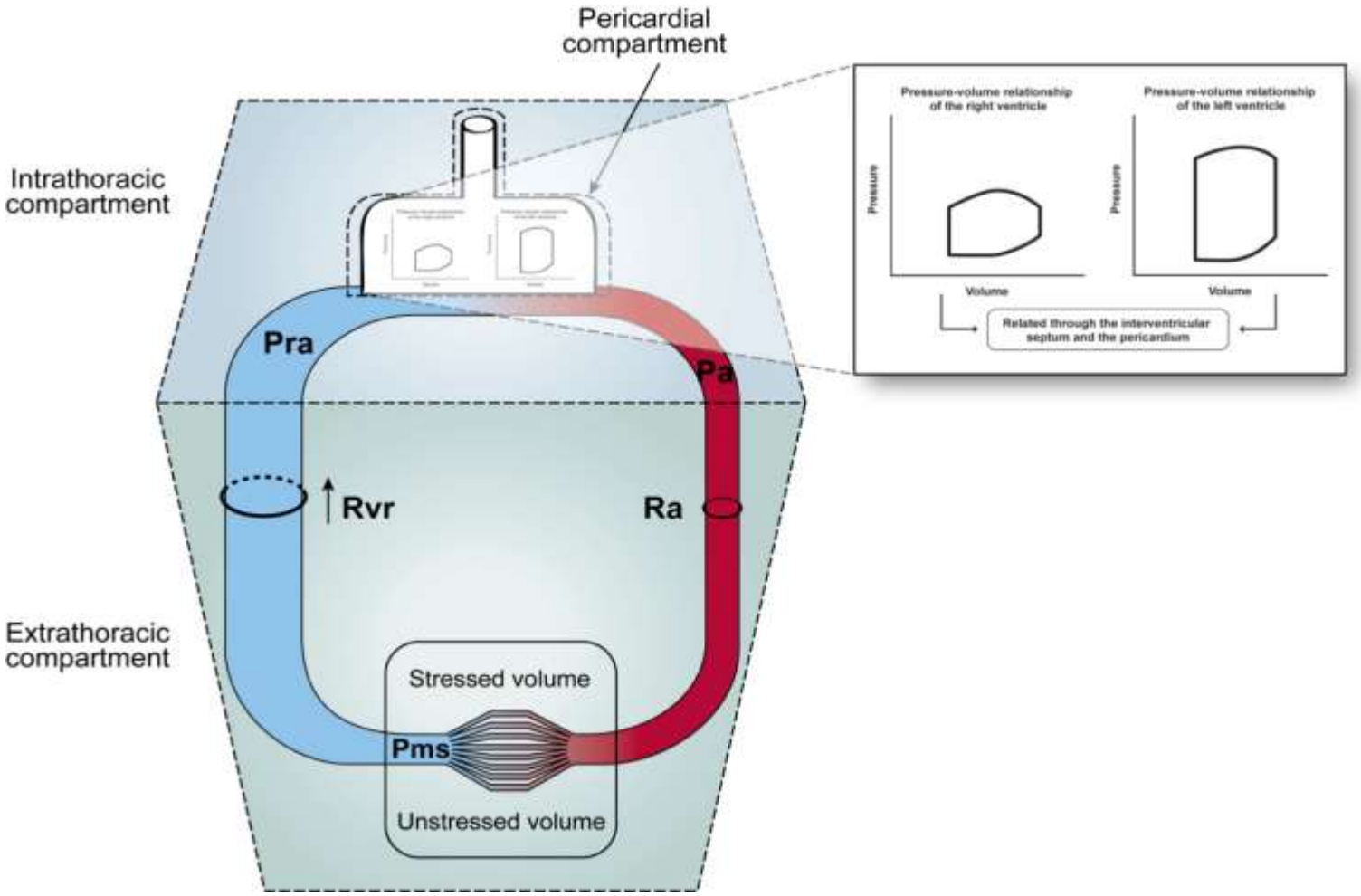

Figure 3 Venous return and pressure-volume loop concept

The circulatory system can be divided into an intrathoracic and an extrathoracic compartment. Illustrated in red is the arterial system and in blue, the venous system. Most of the blood volume (~70%) lies in the venous system. The mean systemic pressure (Pms) is determined by the stressed volume (~30% of blood volume). The cardiac pump has two components, the right and the left ventricles, defined by their

respective pressure-volume loops (simplified). Both ventricles are connected together through the pericardium and the interventricular septum. The function and interaction between both ventricles will determine right atrial pressure (Pra). Blood returning back to the heart, or the venous return, will be dependent on the pressure gradient between the peripheral pressure, or Pms, and the central pressure, or Pra. Furthermore, any conditions increasing the resistance to venous return (Rvr), for instance compression of the inferior vena cava, will reduce venous return and consequently cardiac output. (Pa, systemic arterial pressure; Ra, arterial resistance)

The combination of conventional hemodynamic monitoring, FOCCUS ± TEE allows the determination of the causes of hemodynamic instability.[20] However, so far, a systematic approach in the diagnosis of hemodynamic instability using conventional hemodynamic, FOCCUS ± TEE could be useful in the OR, recovery room and ICU. This combined approach can be used to determine the causes of hemodynamic instability. The causes of hemodynamic instability resulting in reduced venous return or cardiac output and leading to difficult separation from CPB are a reduction in Pms, an increase in Pra and an increase in Rvr (Table 1).

Table 1 Mechanism of hemodynamic instability

1) Reduction in mean systemic pressure:
    - Reduction in stressed volume:
        - Hemorrhagic shock:
            - External hemorrhage
            - Internal: hemothorax, peritoneal hemorrhage, retroperitoneal hemorrrhage, gastrointestinal hemorrhage
    - Increased in compliance
        - Drug-induced vasodilatation
        - Anaphylaxis
        - Vasoplegic syndrome
        - Sepsis
        - Adrenal insufficiency
2) Increased right atrial pressure
    - Left and right ventricular systolic dysfunction
    - Left and right ventricular diastolic dysfunction
    - Left and right outflow tract obstruction
    - Left and right embolism
    - Aortic and mitral patient-prosthesis mismatch
    - Hypoxia and hypercapnia
    - Pulmonary reperfusion syndrome
3) Increased resistance to venous return
    - Compartment syndrome
        - Pericardial tamponade
        - Mediastinal: post cardiopulmonary bypass
        - Pleural: hemothorax and pneumothorax
        - Abdominal: intrinsic, extrinsic or parietal
    - Vena cava syndrome
        - Inferior
        - Superior

Anesthesiologists are the critical care physicians of the operating and the recovery rooms. Echocardiography, both FOCCUS and TEE are becoming an integral part of the training curriculum of critical care physicians. Anesthesiologists are rapidly understanding the importance of acquiring these essential skills in resuscitation.

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