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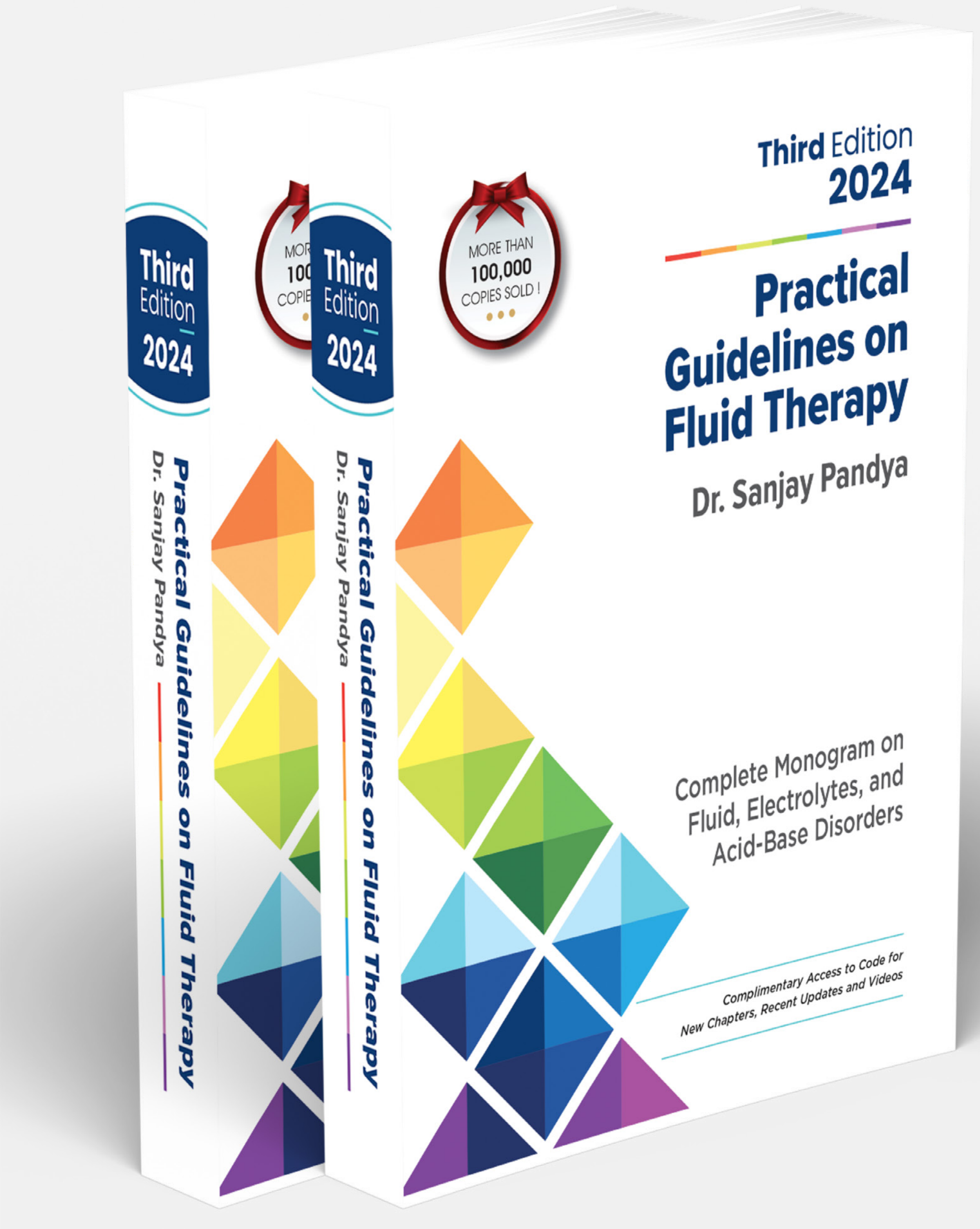
Chapter 16:

Basic and Non-Invasive Hemodynamic Monitoring Techniques



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16 Basic and Non-Invasive Hemodynamic Monitoring Techniques

Various basic and non-invasive methods are routinely used in clinical practice, which help to plan, administer, and monitor fluid therapy in non-critical patients. The basic and non-invasive monitoring modalities are not the standard methods for hemodynamic monitoring and lack specificity and sensitivity, but it provides valuable help in the initial assessment and management of shock. Non-invasive cardiac output monitoring is discussed in detail separately in the subsequent chapter.

NON-INVASIVE BLOOD PRESSURE MEASUREMENT

Blood pressure monitoring is a basic and easy non-invasive parameter for hemodynamic monitoring in all patients.

Non-invasive blood pressure is measured either intermittently or continuously. Intermittently blood pressure is measured by an inflatable occluding cuff using a manual sphygmomanometer or automated oscillometric devices. Continuously blood pressure is measured by newer methods such as volume clamp method or arterial applanation tonometry. Details of these methods are included in the non-invasive cardiac output monitoring part of the Chapter 19 on "Cardiac Output Monitoring."

In mild hypovolemia, compensatory mechanisms prevent a fall in blood pressure. So, normal blood pressure does not exclude hypovolemia.

Postural hypotension is a fall of at least 20 mm Hg systolic blood pressure or 10 mm Hg diastolic blood pressure within 3 minutes of standing [1]. Postural hypotension is a strong indicator of hypovolemia in the absence of other causes such as medications, autonomic neuropathy, etc.

Mean arterial pressure is a better parameter for assessing tissue perfusion than systolic blood pressure (SBP) and diastolic blood pressure (DBP). Mean arterial pressure (MAP) is the average arterial pressure in one cardiac cycle.

Formula to calculate MAP is:

$$MAP = [SBP + (2 \times DBP)]/3$$

MAP of at least 60 mm Hg is necessary to maintain the adequate perfusion of vital organs. Recent Surviving Sepsis Campaign Guidelines recommended an initial MAP target of 65 mm Hg in patients with septic shock requiring vasopressors [2].

PULSE OXIMETRY

Pulse oximetry is used routinely worldwide for the rapid diagnosis of hypoxemia; It is referred to as "the fifth vital sign" [3].

Pulse oximetry is an inexpensive, non-invasive, compact, portable, and reliable technique that can continuously, rapidly, and accurately estimate arterial oxygen saturation (SpO_2) and thereby provide important information about tissue oxygenation.

Early diagnosis of hypoxemia is difficult clinically. Cyanosis is its late sign, so a pulse oximeter is used to monitor all types of patients at risk of developing hypoxemia [4]. In this easy-to-use method, the sensor probe is usually placed on fingers, toes, or ear lobes which measures two parameters, the oxygen saturation of hemoglobin in arterial blood and the pulse rate.

By using spectrophotometry, a pulse oximeter differentiates oxygenated versus non-oxygenated hemoglobin in the arterial blood and thereby measures the percentage of oxygenated hemoglobin in the blood (i.e., SpO_2). The accuracy of pulse oximeters is generally reliable when SpO_2 is in the range of 70% to 100%, but it is poor when SpO_2 values are <70% [5].

The normal value of SpO_2 in a healthy person is 96% to 100%, which correlates to the normal range of PaO_2 (i.e., 80 to 100 mm Hg). Less than 90% SpO_2 correlates to a PaO_2 of 60 mm Hg or less, which suggests significant hypoxemia, which can be dangerous [6]. When SpO_2 falls below 90%, the PaO_2 drops very rapidly. PaO_2 will be as low as 60–45 mm Hg when SpO_2 reduces from 90 to 80%, and when SpO_2 falls below 80%, it predicts life-threatening hypoxemia as the PaO_2 will be just 40 mm of Hg or even lesser [6].

Factors that can affect the accuracy of pulse oximetry are cold extremities, hypotension, poor circulation, patient movements, nail polish use, abnormal hemoglobins, and severe anemia [7].

Use of intravenous dyes like methylene blue (to treat methemoglobinemia, or to diagnose ureteral injury during surgical procedures) can result in low SpO_2 reading from a pulse oximeter but normal PaO_2 from a standard blood gas machine (known as "oxygen saturation gap") [8].

CONTINUOUS ELECTROCARDIOGRAPHY

Continuous electrocardiography monitoring is a standard practice in all unstable patients because it provides crucial information about rate, rhythm abnormality, cardiac ischemia, and abnormalities due to electrolyte abnormalities. Lead II and V1 are the most sensitive for detecting P waves and cardiac arrhythmias, while lead II, V2, and V5 are the most sensitive for detecting myocardial ischemia.

ECHOCARDIOGRAPHY

Echocardiography is a safe, simple, readily available, unique, and effective method for the initial assessment of hemodynamically unstable patients. Echocardiography is a widely used and preferred modality that helps to diagnose, monitor, manage, and follow up various clinical problems mentioned below [9–12].

- For the initial assessment of patients with hypovolemia, hemodynamic instability, and shock where it helps to differentiate various types of shock.
- To assess acute respiratory distress syndrome, right ventricular dysfunction, respiratory failure, or hypoxemia of unknown etiology.
- To diagnose pericardial effusion, cardiac tamponade, valvular obstructive or regurgitation lesions, cardiac thrombus, infective endocarditis, and pulmonary embolism.
- To assess the fluid status and by frequent evaluation guides in the tailored management of unstable patients.
- To determine the fluid responsiveness by measuring the size of the vena cava and assessing the effect of respiration, fluid challenge, and passive leg raising on it.

Respiratory variation in the vena cava, left ventricular function, right ventricular function size, and movement of the interventricular septum are the major parameters measured by echocardiography. These parameters are helpful in hemodynamic assessment and monitoring. In addition, echocardiography also provides information about cardiac output and pulmonary artery pressure, which helps to optimize patient management.

Two different echocardiography techniques used for hemodynamic monitoring are transthoracic echocardiography and transesophageal echocardiography.

A. Transthoracic echocardiography (TTE)

It is a simple tool in which an ultrasonic probe is placed on the chest or epigastrium of the subject to assess the heart and its blood vessels. For the hemodynamic assessment in patients with hypotension, TTE is performed first because it is a readily available, non-invasive, accurate, and precise technique that can be performed quickly at the bedside [13].

B. Transoesophageal echocardiography (TEE)

In TEE ultrasonic probe is placed into the esophagus and usually in a ventilated patient under sedation. As the probe is much closer to the heart in TEE, this method provides superior image quality of the heart and great vessels. Because TEE provides additional and more accurate information, it has higher diagnostic accuracy than TTE [14].

TEE is used selectively in the perioperative management of unstable surgical patients (e.g., cardiac surgical procedures, laparotomy, etc.) and in patients where TTE is not possible or provides insufficient information (i.e., chest wall injury, obese patients with poor echocardiographic window, etc.).

Although TEE provides accurate and more information than TTE, it is used in selected indications and not used routinely. Major limitations of this technique are higher cost, time-consuming method (compared to TTE), minimally invasive procedure (usually needs tracheal intubation), can be performed only on one patient at a time, and needs cleaning and disinfection after each use.

ULTRASONOGRAM

In hemodynamically unstable patients, ultrasonography may be useful in determining underlying causes for shock, such as hidden blood loss (intrathoracic intraabdominal, retroperitoneal, bladder, or extremity hematoma) or detecting the source of sepsis. Timely treatment of such potentially reversible causes of hemodynamic instability can be life-saving. Follow-up ultrasonography also helps to assess the treatment response (change in the volume of blood in pleural, pericardial or abdominal space, or improvement in the source of the infection).

LUNG ULTRASOUND

Lung ultrasound (LUS) is an increasingly used modality for assessing lung status and hemodynamic monitoring in critically unstable patients. Lung ultrasound is an easy-to-use, radiation-free, safe, less expensive, non-invasive, reliable, and reproducible bedside tool that helps in diagnosis as well as planning optimum fluid administration [15, 16].

Lung ultrasound is a powerful tool that helps to assess the fluid status and diagnose or exclude pleural effusion, pneumonia, and pneumothorax [17, 18]. In addition, bedside lung ultrasound is an effective and helpful tool for the initial evaluation of a patient with hypotension and shock, guiding fluid administration, monitoring treatment response, and detecting fluid overload early [19, 20].

Lung ultrasound is a more accurate, faster, and more convenient imaging technique than chest X-rays in emergency departments [20–22].

A. Pulmonary edema

Lung ultrasound is a useful tool that can reliably and sensitively detect pulmonary edema [16]. By assessing the volume of extravascular lung water, lung ultrasound can diagnose pulmonary edema before detecting it by any clinical signs [23]. Extravascular lung water is the amount of water in the lungs outside the pulmonary circulation, i.e., accumulated in the interstitial and alveolar spaces [24]. Therefore, lung ultrasound is recommended as a first-line test to detect pulmonary congestion, which helps in the better management of fluid administration, monitoring the response of fluid therapy, and avoiding iatrogenic pulmonary edema [25–27].

On lung ultrasound, the presence and numbers of B-lines (also termed ultrasound lung comets) reflect the volume of extravascular lung water [28, 29]. The presence of B-lines is unanimously considered a pathological finding, and B-lines are generally absent in euvolemic patients (suggests "Dry" lungs) [30, 31].

B-lines score (BLS) is the sum of all B-lines used to quantify pulmonary congestion [32]. The normal value of BLS is <5, and >15 BLS reflects moderate/severe pulmonary congestion [33]. More than three B-lines in a particular view on lung ultrasound is also a reliable clue for pulmonary edema [34]. The new appearance of B-lines is an early sign of pulmonary congestion and guides clinicians to discontinue fluid administration [35].

B. Pleural effusion, consolidations and pneumothorax

In pleural effusion, lung ultrasonography is an essential tool in diagnosing, quantifying, following the course, decision-making to drain, deciding the best puncture site for tapping, guiding the drainage insertion procedure, and diagnosing co-existing lung diseases [36–39]. In pneumonia, bedside lung ultrasound is a first-line diagnostic tool with high accuracy (94% sensitivity and 96% specificity) [40–43]. In addition, lung ultrasound is a novel tool with high accuracy and reliability in diagnosing pneumothorax (91% sensitivity and 98% specificity) [44–46].

X-RAY CHEST

Chest X-ray (CXR) is routinely used in critical, unstable patients. The major advantage of chest X-rays is immediate panoramic imaging of the thoracic structures, which provides comprehensive information and helps clinicians to suspect or exclude many pulmonary disorders [47]. However, frequent exposure of X-rays carries the risk of radiation.

In hemodynamically unstable patients, chest X-ray helps to detect fluid overload, pleural effusion, pneumonia, pneumothorax, and complications of shock such as acute respiratory distress syndrome, pulmonary embolism, and aspiration pneumonia and provides information about cardiac size and shape. In addition, a chest X-ray is frequently taken after placement of the central line to check the position of the catheter tip and to rule out iatrogenic pneumothorax.

Common chest X-ray findings of fluid overload are cardiomegaly, septal Karley B-lines, congestive vascular hilum, bilateral diffuse perihilar alveolar infiltrates in a butterfly distribution suggestive of pulmonary edema, and signs of pleural effusion. A chest X-ray is not a very sensitive or specific diagnostic test for most of these disorders, but it may be a first step in providing some important clues.

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