CHAPTER 135

Noninvasive Methods of Fluid Status Assessment in Critically Ill Patients

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Objectives

This chapter will:

1. Discuss the importance of fluid status assessment in the setting of the intensive care unit and the correlation between fluid overload and adverse outcomes in critically ill patients.
2. Describe noninvasive methods to assess fluid status (i.e., physical examination, fluid balance recording, chest radiography, ultrasonography techniques) and their role in the management of intensive care patients.
3. Focus on bioimpedance methods to estimate fluid status and present the results from the most recent studies.

Accurate fluid management in patients admitted to the intensive care unit (ICU) is still one of the most challenging and important tasks for critical care physicians. Although the advantages of early fluid resuscitation have been recognized, several studies have demonstrated that fluid administration beyond the correction of hypovolemia is associated with adverse outcomes in critically ill patients.[1–13] Despite progress in the standard intensive care, the assessment of fluid status is still complex and requires an in-depth knowledge of body fluid homeostasis. Nowadays, the treatment of critically ill patients in the setting of the ICU requires a multidisciplinary approach to achieve better outcomes, mainly because many of these patients present with problems such as acute kidney injury and fluid and electrolyte disorders.

Fluid overload (FO) is a very common situation in patients among ICUs all around the world; some studies have reported prevalence between 62% and 64.8%,[11,13] and it is widely accepted that FO is associated with an increase in mortality in critically ill patients.[3,4,6,12,13]

In the acute setting of shock, as well as in the acute congestive decompensated states, physical examination may respectively provide signs of hypovolemia or venous congestion that should lead to prompt treatment. Nevertheless, physical examination should be aided by other tools to improve assessment of fluid status and guide therapeutic decisions. Although the gold standard method is isotope dilution, unfortunately it is difficult to perform in critically ill patients because of fluid sequestration and abnormal penetration of tracers into cells.[14] In this chapter, we discuss noninvasive methods to assess fluid status and its role in the management of ICU patients. Starting from physical examination, fluid balance recording, and chest radiography (CRX), we list ultrasonography techniques that are explained in depth in another book section and then focus on bioimpedance methods.[14a]

PHYSICAL EXAMINATION AND FLUID BALANCE RECORDING

Physical Examination

The first tool that every physician has to evaluate a patient's volume status is the history and physical examination. Several symptoms and signs can be found depending if the patient is hypovolemic or hypervolemic (Table 135.1). Many of the studies performed in patients presenting with FO were done in heart failure patients; the most prevalent symptom in these patients was dyspnea, present in 87% to 93% of evaluated individuals.[15,16] In the context of the critically ill, in whom symptoms are difficult to evaluate, edema and weight gain were the most recognized signs.[17]

TABLE 135.1

Summary of Symptoms and Signs Detectable in Hypovolemic and Hypervolemic Patients

HYPOVOLEMIA	HYPERVOLEMIA
Symptoms	**Symptoms**
Agitation	Dyspnea on exertion
Confusion	Edema
Fatigue, lethargy	Orthopnea
Thirst	Paroxysmal nocturnal dyspnea
Muscle weakness, cramps	Cough
Abdominal pain	Fatigue and weight gain
Thoracic pain	
Signs	**Signs**
Hypotension	Rales
Tachycardia	Lower extremity edema
Dry skin, tongue	Jugular venous distention
Reduced skin turgor	Abdominal-jugular reflux
Delayed capillary filling	Systolic blood pressure >150 mm Hg
Flattened neck veins	Wheezing
Cold and cyanotic extremities	Any murmur
Oliguria, anuria	Third heart sound
	Fourth heart sound
	Ascites

Nevertheless, although it is an easy and rapid way of assessment, clinical examination has several limitations. For example, significant volume overload can occur without edema, edema and intravascular volume depletion can coexist, and the presence of edema can have a wide range of addition contributing causes.[18]

There is a significant difference when comparing clinical evaluation with invasive volume assessment techniques. Duane[19] evaluated the accuracy of diagnosing volume overload with Swan-Ganz catheter, echocardiography, and clinical assessment in ICU patients with hypotension, pulmonary edema, or both. He found a sensitivity of 100%, 77%, and 40%, respectively, with a false-positive rate of 0, 62%, and 21%. Because of these and other findings, the assessment of volume status in ICU patients should be aided by other noninvasive and invasive methods. To achieve this objective, cumulative fluid balance (CFB) recording, serial body weight (BW) measurements, and CRX are used commonly to complete the task.

Fluid Balance Recording

Fluid balance charts are used frequently by nurses in the ICU setting to assess the patient's fluid status. In these charts, the type and amount of fluid administered and lost by each patient are recorded every day. Using this method, daily fluid balance is defined as the arithmetical difference between fluid administered (e.g., intravenous fluids, blood products, enteral fluids) and fluid lost (e.g., urine output, blood losses, enteral losses, drain losses).[6] CFB can be defined as the sum of the daily fluid balances over a determined period of time. Most studies in the literature calculated FO by dividing the CFB by the ICU admission weight; this value is expressed as a percentage.[4,5,12] Fluid balance charts are used widespread and, in some ICUs around the globe, they constitute the only way to estimate FO in critically ill patients. Although useful, fluid balance recording has many limitations, and it can result in inaccurate data. Arithmetic errors, complicated recording formats, and ignoring insensible losses (IL) (IL = 10 mL/kg of BW/day; if body temperature is higher than 37.8°C, add 500 mL/day) are some of the most common problems.[20]

Body Weight Measurement

A change in BW, and by consequence, an estimate of fluctuations in total body water (TBW) is another tool to asses FO in critically ill patients. The measurements often are done at admission and discharge from the ICU, but, in some centers, they are performed daily. Some of the problems related to this practice are the great difficulty to perform a day-to-day measurement in the critically ill and that loss of muscle and fat mass may contribute to weight loss other than water and mask any further fluid gain.[18] There are several devices such as beds and chairs with built-in scales that can measure BW in the ICU setting. These devices are not widely available because of their high cost. Recent studies have demonstrated that the cost-benefit relationship of these devices does not justify the great investment. These studies found a poor agreement between measurements of FO performed by regular scale, bed scale, and fluid balance recording.[21,22] Thus it is not recommended to substitute fluid balance recording with bed scales weight measurements. Nevertheless, the concomitant use could be somehow useful.

CHEST RADIOGRAPHY

CRX, a fast and cheap noninvasive diagnostic tool, is a standard practice in assessing FO in critically ill patients, especially when pulmonary edema is suspected. Kennedy et al.[23] found that congestive heart failure could be diagnosed correctly with CRX by 73% to 91% of emergency department physicians (ability depending on the years of training) and 95% of radiologists, with specificity of 96% and sensitivity of 59%. Volume overload often manifests with the following radiographic signs: dilated upper lobe vessels, cardiomegaly, interstitial edema, enlarged pulmonary artery, pleural effusion, alveolar edema, prominent superior vena cava, and Kerley lines.[16] The vascular pedicle width (VPW) is another method to evaluate a CRX for FO. It is measured by dropping a perpendicular line from the point at which the left subclavian artery exits the aortic arch and measuring across the point at which the superior vena cava crosses the right mainstem bronchus.[15] A VPW cutoff value of 70 mm in addition to a cardiothoracic ratio (cardiac width divided by thoracic width) higher than 0.55 significantly improves the accuracy of CRX to determine fluid status.[24] Limitations on the accuracy of CRX to determine volume status depend greatly on the technique used to obtain the image. Supine, anteroposterior, and posteroanterior projections, as well as the patient's rotation, can affect the sensitivity and specificity of this tool to correctly assess volume status.

BIOELECTRICAL IMPEDANCE ANALYSIS

Bioelectrical impedance analysis (BIA) is a property-based method of electrical conductance of body tissues. Total body impedance (Z) derives from resistance (R) and reactance (Xc). R and Xc represent the opposition to an alternating electric flow exerted, respectively, by the intra- and extracellular electrolyte solutions and by the interfaces of cell membranes and tissues. Although R reflects the patient's fluid status, Xc is indicative of patient's nutritional status. When total body impedance is measured, electrodes are applied commonly on the right hand and foot, according to the most used "hand to foot approach." Bioimpedance is performed with the patient in a supine position without touching metal objects. The angles between the upper limbs and trunk and between the legs are 30 and 45 degrees, respectively. Skin should be cleaned with alcohol or saline before the application of electrodes. Comparing the human body to a cylindrical conductor, its impedance is directly proportional to its length and inversely proportional to its transverse area. Therefore total body impedance is determined by limbs up to 90% and by trunk up to 10%, thus being of scarce impact on the results of ascites and pleural effusion.

In biologic systems, although lower-frequency currents flow mainly in the extracellular space, currents with higher frequencies pass through extracellular and intracellular compartments. Single-frequency BIA (SF-BIA), which is one of the earliest proposed methods for the estimation of body compartments, is based on electric models achieved through regression equations. Unfortunately, for many years, it has been found to be invalid in subjects with altered hydration status, thus limiting its clinical use. Analysis of bioimpedance obtained using more than two frequency currents is known as multiple-frequency BIA (MF-BIA). MF-BIA has been reported to better predict TBW than SF-BIA in critically ill patients.[25]

Bioelectrical Impedance Vector Analysis

Bioelectrical impedance vector analysis (BIVA) is an easy-to-use single-frequency technique. Although BIVA can be performed using any current frequencies, the optimal performance is achieved with an operating frequency of 50 kHz, which allows impedance measurements with the best signal-to-noise ratio. In BIVA, R and Xc, indexed to height (H), which is the conductor length, are represented graphically in a nomogram: RXc graph simultaneously describes hydration status and soft tissue mass compared with the standard deviation ellipses. Taking into account the major axis of the graph, a shorter resulting vector identifies a higher content of body fluids, reaching extremes out of the pole[26] (Fig. 135.1). This technique has been validated in healthy individuals,[26,27] and it is used widely in maintenance hemodialysis and peritoneal dialysis patients.[28–30] In spite of previous studies reporting unclear and controversial evidences about the effectiveness of bioimpedance in ICU patients, modern BIVA technique seems to be reliable, especially to detect hydration changes in repeated measurements. To allow an easier interpretation, an algorithm has been developed to finally convert bioelectrical parameters into a synthetic measure of lean body mass hydration percentage. According to this numerical scale, patients can be classified as dehydrated, normohydrated, and hyperhydrated. The normal level of hydration has been set between 72.7% and 74.3% of lean body mass (class 0). Higher and lower values represent states of hyperhydration and dehydration, respectively. Dehydration is classified into mild (class –1: >71%–72.7%), moderate (class –2: >69%–71%) and severe (class –3: ≤69%). Similarly,

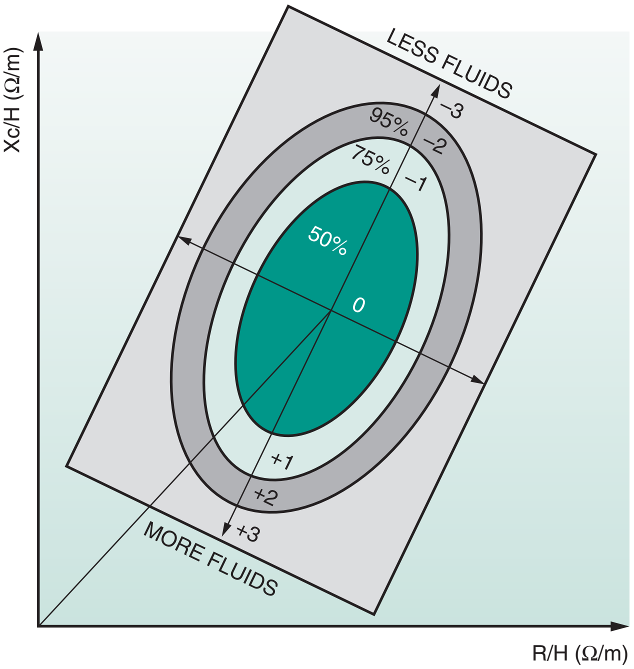

FIGURE 135.1 Bioimpedance vector analysis tolerance ellipses. RXc graph is represented together with the numeric scale. The smallest oval corresponds to 50th percentile, middle oval to 75th percentile, and largest oval to 95th percentile. A shorter vector indicates fluid overload, whereas a larger vector indicates volume depletion. According to the numeric scale, patients are classified in 7 BIVA-hydration classes. The normal level of hydration corresponds to BIVA-hydration class 0. Higher and lower values represent states of hyperhydration and dehydration, respectively.

hyperhydration is classified into mild (class +1: >74.3%–81%), moderate (class +2: >81%–87%) and severe (class +3: >87%)[31] (see Fig. 135.1).

In a recent study, the relationship between BIVA-measured hydration and changes in CFB was assessed in 61 critically ill patients. Authors found an increase in BIVA-measured hydration in patients with CFB greater than 1L and directional changes in BIVA-measured hydration were consistent with directional changes in fluid balance. However, a median fluid loss of 2.4L was required for a significant corresponding directional change in BIVA-measured hydration to occur. This may suggest that BIVA is insensitive to smaller fluid balance changes in critically ill patients or, alternatively, may indicate the inadequacy of fluid balance recording in ICU.[32] This may be consistent with our recent findings. In our study, we compared BIVA and CFB recording in the assessment of hydration status and thus in predicting mortality in ICU patients. We performed two multivariate logistic regression models with ICU mortality as the response variable: in the BIVA model, we evaluated the association between ICU mortality and the presence of moderate and severe hyperhydration; in the FO model, the predictor variables tested were FO between 5% and 9.99% and FO at or exceeding 10%. Severe BIVA-measured hyperhydration was the only variable found to be significantly associated with ICU mortality. Moreover, all indexes (Akaike information criterion, sensitivity, and specificity) assess the superiority of BIVA model when compared with the other.[13] Another study that enrolled patients with acute heart failure demonstrated a high predictive value for cardiovascular events at 90 days of BIVA-measured hyperhydration when combined with clinical signs.[33]

In conclusion, despite the fact that intervention studies still are required, there is growing evidence that BIVA may add useful information to guide fluid management in critically ill patients.

Bioelectrical Impedance Spectroscopy

Bioelectrical impedance spectroscopy (BIS) relies on an electrical model obtained using a broad band of frequency. The determination of R at zero frequency and at infinity frequency is used to predict extracellular compartment volume and TBW, respectively.

Although BIA and BIS have demonstrated a high correlation with direct estimation methods of TBW[34] in maintenance haemodialysis patients, BIS seems to be more accurate in assessing fluid volumes.[35,36] Nevertheless, BIS requires knowledge of the patient's weight, which is not always available in the ICU setting,[37] as previously discussed.

ULTRASONOGRAPHY TECHNIQUES

Ultrasound assessment of the inferior vena cava (IVC) and lung parenchyma are used commonly in the ICU to evaluate a patient's fluid status. The reliability and the ease of measurement at the patient's bedside has contributed to the widespread adoption of these methods by critical care physicians. Technical details of ultrasonography techniques are provided in the appropriate book section.[14a]

Lung Comet-Tails

Lung comet-tails are ultrasound artifacts generated by thickened subpleural septa; they can be considered as ultrasonographic corresponding to the Kerley lines at CRX and have been validated recently for the semiquantification of pulmonary congestion.[38] In patients with heart failure, the number of lung comet-tails correlates with more traditional tools in diagnosing and monitoring resolution of pulmonary congestion.[39,40] A recent study by Pivetta et al. demonstrated a high sensitivity (97%) and specificity (97.4%) of lung comet-tails' evaluation in differentiating acute heart failure from noncardiac causes of dyspnea in patients in the emergency department.[41] Furthermore, the number of lung comet-tails varies before and after a dialytic session,[42,43] and some data suggest its usefulness to manage ideal body weight in hemodialysis patients.[44] Nevertheless, although lung comet-tails usually are due to pulmonary congestion, they also can be present in other pathologic conditions not rarely encountered in the ICU, such as acute respiratory distress syndrome, interstitial diseases, pneumonia, lung fibrosis, and laceration, thus reducing their specificity.[45]

Inferior Vena Cava Ultrasound

Several indices related to IVC measures have been proposed to evaluate patient's fluid status. Nowadays, the most used are the indexed vena cava diameter (VCDi) and the IVC collapsibility index (IVCCI). They are computed as follows:

$$\text{VCDi} = \text{Maximal IVC diameter } (\text{IVC}_{\max})/\text{body surface area } (\text{m}^2)$$

$$\text{IVCCI } (\%) = [(\text{IVC}_{\max} - \text{IVC}_{\min})/\text{IVC}_{\max}] * 100$$

These indices can be determined easily and provide a rapid assessment of patient's volume status. When VCDi is greater than 1.5 mm/m^2 and IVCCI is less than 40%, they are indicative of hypervolemia. IVC ultrasound findings, in hypovolemic and hypervolemic patients, closely correlate with invasive methods for fluid assessment.[46] Similarly, variation in the indices may improve treatment monitoring.[47,48]

CONCLUSION

Despite the incredible development of technology applied to medicine, the correct assessment of hydration status and the identification of FO is still a challenging task. The gold standard method, isotope dilution, is impractical and mostly unavailable in clinical settings. Therefore critical care physicians should rely on other methods to classify patients according to fluid balance, to prevent worse outcomes, and diminish mortality. Noninvasive methods such as physical examination, fluid balance recording, and chest radiography are widely available, but their use can lead to inaccurate data and mislead decisions, especially when used alone. Other noninvasive methods such as BIA, BIS, and diverse ultrasonography techniques have demonstrated their diagnostic value. The information provided by these methods has been correlated correctly with fluid status. The concomitant use of diverse noninvasive methods could be the best approach to correct fluid status assessment. This approach could lead to better therapeutic decisions and better patient outcomes.

Key Points

1. Several studies have demonstrated a positive correlation between fluid overload and adverse outcomes in critically ill patients.
2. Despite progress in the standards of intensive care, the assessment of fluid status and consequent treatment are still complex and require an in-depth knowledge of body fluid homeostasis.
3. Isotope dilution is the gold standard method to asses fluid status, but it is unpractical and mostly unavailable in clinical settings.
4. History and physical examination are the first tools that physicians have to evaluate a patient's volume status; because clinical examination has several limitations, it should be aided by cumulative fluid balance recording, serial body weight measurements, and chest radiography.
5. Bioelectrical impedance analysis is a property-based method of electrical conductance of body tissues.
6. Bioelectrical impedance vector analysis (BIVA) is an easy-to-use single-frequency technique, extensively used in healthy individuals, as well as in maintenance hemodialysis and peritoneal dialysis patients.
7. Recent studies have demonstrated the reliability of BIVA measurements in critically ill patients and the correlation between hyperhydration measured by BIVA and long-term mortality in patients admitted to the intensive care unit.
8. The concomitant use of diverse noninvasive methods could be the best approach to correct fluid status assessment.

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Full references for this chapter can be found on www.expertconsult.com.

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