SPECIAL ARTICLE

Cardio circulatory and respiratory monitoring of mechanically ventilated critically ill patients

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Received: 4 Jun 2018
Reviewed: 6 Jun 2018
Accepted: 13 Sep 2018

ABSTRACT

Respiratory support in terms of mechanical ventilation is very common in critically ill patients. These patients are often hemodynamically unstable too. The mechano-physiology of mechanical ventilation also affects other organ system and needs assessment and management accordingly. The procedure is not devoid of complication. It also has potential to failure to achieve the treatment objective requiring frequent assessment and adjustment. There is a very close temporal relationship between patients monitoring and management decision in critically ill patients in critical care practice. Early and appropriate information from monitoring can lead to better outcome including reduced mortality. The present review is intended to briefly highlight the current opinions and strategies for cardio circulatory and respiratory monitoring in such patients in critical care unit.

Citation: Karim HMR. Cardio circulatory and respiratory monitoring of mechanically ventilated critically ill patients. Anaesth Pain & Intensive Care 2018;22 Suppl 1:S142-S149

CARDIO CIRCULATORY MONITORING

Mechanically ventilated patients are mostly critically ill and hemodynamic instability is very common in such patients. Weil MH defined hemodynamic instability as either simply one or more out-of range measurements but not necessarily pathological values, or a clinical condition of either perfusion failure clinically presented as circulatory shock and/or advanced heart failure.[1] As circulation / pumping the blood is the function of the heart, it becomes essential to monitor the functional status or hemodynamics in such patients. Hemodynamics monitoring can be described under two headings, i.e. basic and advanced. Basic monitoring includes clinical assessment, assessment of global perfusion and preload and fluid responsiveness monitoring. The advanced monitoring includes cardiac contractility and output monitoring and tissue perfusion.[2]

Clinical examination still remains useful tool and an important initial step in the diagnosis and risk stratification of hemodynamically unstable patients. Parameters like high pulse rate and low volume, increased respiratory rate, cold and clammy periphery, low blood pressure, low urine output, increased capillary refilling time etc indicates poor compromised hemodynamics.[3] Although tachycardia is a common feature of hypovolaemia and hemodynamic instability, bradycardia can also be associated with low cardiac output. Therefore all such patients should be monitored for electrocardiography (ECG), blood pressure (BP) and pulse oximetry (SpO_2). Continuous ECG monitoring will help us in detecting both rate and rhythm disturbances. ST segment analysis in the continuous ECG can also detect myocardial ischemia early. Unless indicated blood pressure can be monitored by non-invasive techniques.

Serum lactate level is a marker of global perfusion and elevated levels may represent poor tissue perfusion. It has been even regarded as new emerging vital sign in septic shock patients.[4] Both initial serum lactate level and lactate clearance at a discrete time point is an important prognostic factor in septic shock patients.[5] Therefore, a baseline serum lactate measurements and then follow up can give us information on tissue perfusion, prognosis and indirectly changing hemodynamics.

Central venous oxygen saturation ($ScvO_2$) monitoring have been proposed as a surrogate for venous oxygen saturation (SvO_2) monitoring, which can give idea about oxygen supply/demand or oxygen consumption. As O_2 supply to the tissues is the basic objective behind hemodynamic management and mechanical ventilation etc., critical care physicians are trying to find out an integrative monitoring parameter which will assess global hemodynamic status of critically ill patients more suitably. To reduce measurement error, it is advised to measure $ScvO_2$ from the tip of a central venous catheter placed close to, or within, the right atrium.[6] Although the $ScvO_2$ reflects the balance between oxygen delivery and oxygen consumption directly, the use of this monitoring parameters has remained in controversy. It was suggested as even a parameters to be monitored in goal directed therapy for septic shock patients but Meta-analysis failed find the benefit of early goal directed therapy itself.[7,8,9] However, the new guideline and Surviving Sepsis Campaign Bundle do not mention the use of it.[10,11] Data also indicates that lactate clearance in sepsis is non-inferior to continuous $ScVO_2$ monitoring.[12]

If a patient is hypotensive, then we should know whether the hypotension is because of low preload. It is also important to know whether the patient is fluid responsive or not. Traditionally central venous pressure (CVP) had been used for knowing the preload status and increasing CVP value indicates increasing preload. Although the extreme values can predict fluid status satisfactorily, a single value of CVP has very less implications and is having many limitations for using as guide for resuscitation. However, CVP values provide important information about the cardio circulatory status and should not be abandoned yet.[13]

At present both static and dynamic parameters are used for monitoring preload in critically ill patients. Static parameters monitored can be pressure related, i.e. CVP and pulmonary artery occlusion pressure and volume related i.e. global end-diastolic volume (GEDV) and left ventricular end diastolic volume (LVEDV). Whereas the dynamic parameters monitored are variations in the pressure like pulse pressure variation (PPV), systolic pressure variation (SPV); volume variations like stroke volume variation (SVV), collapsibility of inferior vena cava and superior vena cava. Positive pressure ventilation in a patient produces physiological effects on the right and left sides of the heart which in turn leads to changing preload. During inspiration, increased LV filling causes an increase in LV stroke volume (SV) and opposite happens during expiration. In hypovolemic patients, these changes in LV SV are most marked leading to changes in PPV, SVV, and SPV etc. A PPV of > 13% and SVV of > 10% are considered as fluid responsive. Static preload monitoring like CVP has shown to be ineffective in predicting fluid responsiveness,[14] and dynamic parameters are better than static parameters to be used as predictor of preload responsiveness.[15]

The commonly employed rapid and easy way of assessing fluid responsiveness in the bed side is fluid challenge test. The most commonly practiced fluid challenge (FC) consists in infusing 500 mL of crystalloids or colloids in 20-30 minutes, and considered an increase in cardiac index ≥ 15% as a positive response. However, definite standards for FC administration and evaluation remain undefined.[16] In this context, we should also remember that the proportion of responder decreases with long infusion time.[17] Therefore, some intensivists / critical care physicians use 15 – 20 minutes to transfuse the volume for challenge test. A mini fluid challenge with 100 ml fluid over 1 minute leading to 3 – 4% decrease in PPV and SVV has shown to predict fluid responsiveness accurately in mechanically ventilated patients (tidal volume < 8ml/kg of ideal body weight) with circulatory failure.[18]

In the critical care unit (CCU), fluid responsiveness can be determined by an alternative technique to fluid challenge by performing passive leg raising (PLR) maneuver coupled with SV monitoring.[19] PLR test has shown to be a good predictor of fluid responsiveness in both patients adapted to ventilator versus those with inspiratory efforts as well as between patients in sinus rhythm versus those with arrhythmias.[20]

IVC diameters <12 mm has shown to be predictive of fluid responsiveness while values >20 mm predicted non-responders; diameter of 12 – 20 mm were not predictive at all.[21] IVC collapsibility ≥ 25% has shown to be predictive of fluid responsiveness among spontaneously breathing critically-ill patients.[22] The variations in IVC with respiration can predict fluid responsiveness even in mechanically ventilated patients.[23] It is to be remembered that in a spontaneously breathing patient, the IVC collapses in inspiration, whereas in patients with mechanical ventilation the IVC dilates.

Echocardiography allows to measure different volumes and function of heart directly. Bedside echocardiography is a versatile and accurate hemodynamic monitoring tool that can be used for hemodynamic management and fluid resuscitation guide in critically ill patients.[24] Although hand held echocardiography appears to have a narrower diagnostic field as compared with conventional transthoracic echocardiography, it can accurately identify diagnoses based on two-dimensional imaging in ventilated critically ill patients.[25] Echocardiographic examinations using miniaturized trans-esophageal echocardiography (TEE) after brief bed-side training has shown to be feasible and of sufficient quality.[26] The use of hemodynamic TEE for monitoring hemodynamic instability has been also reported.[27] However further prospective randomized study will be required to know their specificity, sensitivity and efficacy to recommend the use.

One of the intentions behind the use of hemodynamic monitoring is to promptly identify the circulatory condition and start resuscitation. On the other hand, the ultimate objective of resuscitation is to restore effective tissue oxygenation and cellular metabolism, which needs perfusion to the cellular level. Information gained from global whole-body monitoring may not detect regional organ perfusion abnormalities until they are well advanced.[28] Moreover, increased microcirculation during resuscitation has been shown to be associated with reduced multi organ failure at 24 hours.[29] These facts necessitate the use of peripheral perfusion monitoring. Peripheral perfusion index (PI), tissue oxygen saturation, continuous transcutaneous oxygen measurement, oxygen challenge test (OCT) etc. can be used to monitor peripheral perfusion. In one study with septic patients, the PI and OCT have been shown to be predictive of mortality after resuscitation.[30] However, their use as a monitor to guide for resuscitation cannot be recommended yet and needs further studies.[31] Although regional variables are the best predictors of outcome after stabilization of the critically ill patient with shock, initial resuscitation does not require monitoring of regional variables.[32]

RESPIRATORY MONITORING

Oxygen Saturation:

Monitoring of oxygen saturation is essential and should be continuously monitored.[33] Pulse oximetry can reliably and accurately reflect real arterial oxygen saturation with minimum limitation. Oxygen saturation monitoring using pulse oximetry is important to ensure that adequate oxygen is provided to the patient. It can also help in detecting short, prolonged and recurrent desaturations. The readings can be used as an early warning sign, and decreasing the need for blood gas measurements.[34] In the absence of partial pressure of arterial oxygen (PaO_2) or PaO_2/FiO_2 (FiO_2 _ fraction of oxygen); oxygen saturation (SpO_2) and SpO_2/FiO_2 can be an accurate measure for initial oxygenation assessment.[35] Risk stratification using SpO_2/FiO_2 has shown to be practical and can be used for even moderate to severe acute respiratory distress syndrome (ARDS) / hypoxemic patient on mechanical ventilator.[36, 37] Analyzing the breath-by-breath variation of the photoplethysmographic signals and arterial impedance, pulse oximetry can even now monitor non-invasive, real time hemodynamics of the ventilated patients.[38] However, the pulse oximetry tracings during non-invasive ventilation (NIV) have low specificity. Abnormalities in pulse oximetry tracings are non-specific and do not allow a distinction to be made between, for instance, ventilation perfusion (V/Q) mismatch versus alveolar hypoventilation.[39]

End Tidal Carbon Dioxide ($EtCO_2$):

End tidal carbon dioxide ($EtCO_2$) has a good relation with partial pressure of arterial carbon-di-oxide ($PaCO_2$) and $PaCO_2$ can be grossly calculated from $EtCO_2$. As $PaCO_2$ represents ventilator function, $EtCO_2$ monitoring can supplement clinicians with information regarding ventilation, V/Q mismatch and decision making. The $EtCO_2$ can be monitored by capnography and continuous monitoring in mechanically ventilated patients is advised.[34] However, it cannot replace the $PaCO_2$ measurement by blood gas completely as the gap between $EtCO_2$ and $PaCO_2$ widens in patients of ARDS.[40] The morphology of the capnography also gives valuable information about airflow, response to treatment etc. in mechanically ventilated patients.[41]

Although capnography has shown to be an efficient tool for assessing nocturnal hypoventilation and predicting good compliance with subsequent NIV treatment of patients with amyotrophic lateral sclerosis, $EtCO_2$ measurement using a dedicating naso-buccal sensor was found to be inaccurate to predict both $PaCO_2$ and $PaCO_2$ variations over time in adult patients suffering from acute hypercapnic respiratory failure.[42,43] Transcutaneous CO_2 has shown to reflect $PaCO_2$ accurately in patients with chronic hypoventilation and can detect nocturnal hypoventilation in patients with normal nocturnal SpO_2, and can differentiate nocturnal hypoventilation from other causes of nocturnal hypoxemia.[44] However, it is yet to be widely available and not routinely recommended. As carbon-di-oxide level gives an idea of both hypo and hyperventilation, $EtCO_2$ monitoring and its trend is likely to contribute to the management of the patients despite having its limitations.

It is evident that the non-invasive technologies and monitoring like pulse oximetry and capnography can contribute a lot in the monitoring, assessment and decision making in mechanically ventilated patients.

Arterial Blood Gas Analysis (ABG):

Continuous pulse oximetry and capnography monitoring can even reduce the need of arterial blood gas analysis (ABG) but it cannot substitute the need of blood gas analysis completely.[45] The ABG in addition also gives the information on acid-base status. The ABG can guide clinicians by aiding in establishing diagnosis, guides treatment plan, ventilator and acid/base management.[46]

A prospective, multi-center, randomized, controlled clinical trial found that decreasing $PaCO_2$ by at least 20% or to achieve $PaCO_2$ values lower than 48.1 mm Hg at least 1 hour after the end of an NIV session in Global Initiative for Chronic Obstructive Lung Disease (GOLD) class IV stable chronic obstructive pulmonary disease (COPD) patients reduced the mortality.[47] A univariate analysis has shown that pH, and base excess (BE) is associated with long term prognosis, whereas multivariate analysis identified a BE below 9 mmol/l was associated with better survival patients with COPD and chronic hypercapnic respiratory failure.[48]

Therefore it is regarded as a good practice to monitor pCO_2, pH and their trend intermittently and BE can be monitored.[33] An ABG should be measured after one hour of starting NIV and one hour after every further change in the settings. As a standard ABG should be taken and used to assist in the management plan at 4 hours or earlier in patients who are not clinically improving or judged clinically necessary and again at 12 hours unless the clinical improvement in the patient obviates the need for further ABG analysis.[49]

Venous Blood Gas Analyses:

Meta-analysis on the utility of peripheral venous blood gas analyses in exacerbations of COPD in the emergency department suggests that there is good agreement for pH and HCO_3 values between arterial and peripheral venous blood (pVBG) results in patients with COPD, but not for PaO_2 or $PaCO_2$. [50] A systematic review and meta-analysis on comparison of peripheral venous and arterial blood gas analysis in adults found that pVBG analysis compares well with ABG analysis for pH estimations in adults but not to the $PaCO_2$ or PaO_2.[51] Therefore pVBG analysis cannot completely replace the need of ABG.

Mechanical Ventilation:

Mechanical ventilation is often associated with positive end expiratory pressure which reduces venous return and preload. Therefore it has the ability to change hemodynamics. Mechanical ventilation is also not devoid of complications. Non-invasive ventilation, although non-invasive in nature and usually associated with minor complications; even potentially life threatening serious complications can happen.[52] Modern mechanical ventilators have built-in software which records and stores data. These data can provide valuable information regarding daily use, leaks, obstruction, and patient ventilator synchronization which can be reviewed and utilized for decision making in patient management.[53] Monitoring of the patients' sensorium, respiratory muscle use can also provide us important clinical findings to aid in decision making.

What monitoring to be used and how frequently?

It is now very clear that continuous progression in the monitoring technology and practice has happened over the last two-three decades. The number of technologies and modalities are also increasing year after year. However, use of all the monitoring is not feasible due to multiple factors. Therefore it becomes an important question that what should be the minimum monitoring to be used and how frequently to be used. Unfortunately, we do not have such universally accepted guideline or standards. Moreover, the requirement of monitoring level in different mechanically ventilated patients are likely to be different based on the co-morbidities, severities of illness, organ failure status etc. The level or degree of monitoring even differs with the level of support required, for example, a patient requiring basic respiratory or cardiac support and a patient requiring advanced respiratory or cardiac support will need different levels of monitoring.

A point prevalence data on patient hemodynamics monitoring pattern from ICUs in Germany, Austria, and Switzerland shows that continuous ECG, pulse oximetry, and invasive or non-invasive blood pressure monitoring were used as basic in nearly all patients; majority of the patients also received invasive arterial and central venous catheterization. Extended hemodynamic monitoring for assessment of cardiac output was only performed in only one in eight patients. Mechanical ventilation, the need for catecholamine therapy, and treatment backed by protocols were the strongest independent predictors for the use of extended hemodynamic monitoring.[54] The Task force of the European Society of Intensive Care Medicine recommends further / extended hemodynamic assessment if clinical and basic monitoring is ineffective in determining the type of shock. Non-invasive methods are the suggested initial and preferred choice; echocardiography can be used. Invasive cardiac output monitoring is not recommended as routine but should be used in those patients who are not responding to initial therapy for assessment to response to fluid and inotropes.[55] Insertion of arterial and central venous catheter is recommended in shock not responsive to initial therapy and/or requiring infusion of vasopressors.[55] For monitoring fluid responsiveness and therapy, dynamic parameters are to be used over static and it is recommended to use more than one variable to guide fluid resuscitation.[55]

In patients with respiratory failure, pulse oximetry and cardiac monitoring like ECG should be continuously monitored for the first 12 hours.[49] Clinical parameters like respiratory rate, pulse, blood pressure and consciousness assessment for acutely ill patients is recommended every 15 minutes in the first hour; every 30 minutes in the 1-4 hour period and hourly in the 4-12 hour period. Patient – ventilator synchrony, mask interface, skin condition and degree of leak should be performed at the same time. Arterial blood gases should be taken as a minimum at 1, 4 and 12 hours after the initiation of NIV.[49] Patient-ventilator synchrony, NIV compliance, and mask comfort should be checked regularly. Intensive monitoring is required for COPD patients with pH <7.26.[49] Although no robust data to recommend capnography from intubation to extubation in mechanically ventilated patient, it appears reasonable to monitor it capnography as surrogate of $PaCO_2$.[56]

To summarize, a critically ill mechanically ventilated patient will require continuous ECG, pulse oximetry and capnography, frequent blood pressure monitoring and intermittent ABG as basic. If the patient is also hemodynamically unstable, use of non-invasive monitoring like echocardiography, semi-invasive arterial and central venous catheter based hemodynamics parameters are indicated. Extended hemodynamics monitoring like CO, CI or lung fluid status like EVLW etc will be required in non-responders to initial therapy in level 3 ICUs who require advanced cardiovascular and /or respiratory support and management.[57] Tissue oxygenation monitoring needs further validation and at present it is recommended for research purposes.[55]

CONCLUSION

Cardio circulatory and respiratory monitoring is very much essential in managing critically ill mechanically ventilated patients. As the severity of disease increases, extend of monitoring also increases. Clinical assessment and basic monitoring like continuous ECG, pulse oximetry is must. Although capnography has limitations, considering the fact that it is non-invasive, low cost device which can work as surrogate of $PaCO_2$, continuous monitoring of capnography can be considered as best practice. Intermittent arterial blood gas monitoring can be considered as mandatory in level 2 and 3 ICUs dealing respiratory and cardio circulatory failure patients. Initial lactate as well as lactate clearance is an important monitoring in patients with shock. Basic invasive monitoring like arterial BP and CVP is frequently required in such patients. Present evidence suggests that the point of care ultrasound, echocardiography is also very essential monitoring to be used and probably can be used more frequently. Extended hemodynamic monitoring is not routine but to be reserved for failure to respond to initial therapy. Lastly, no machine or monitor can substitute the best monitor (i.e. intensivist him/herself) till now.

Conflict of interest: None

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