Hemodynamic monitoring and outcome—A physiological appraisal

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Abstract

Hemodynamic monitoring provides us with refined details about the cardiovascular system. In spite of increased availability of the monitoring process and monitoring equipment, hemodynamic monitoring has not significantly improved survival outcome. Care providers should be cognizant of the role of the cardiovascular system and its importance in oxygen delivery to the cells in order to sustain life. Effective hemodynamic monitoring should be able to delineate how well the system is performing in carrying out this role. Different hemodynamic monitors serve in this role to a different extent; some provide very little information on this. The cardiovascular system is only one of the many systems that need to function optimally for survival; others of equal importance include the integrity of the airway, the breathing process, the adequacy of hemoglobin level, and the health of the tissue bed, especially in the brain and the heart. Advances in hemodynamic monitoring with focus on oxygen delivery at the cellular level may ultimately provide the edge to effective monitoring that can impact outcome.

1. Introduction

Hemodynamic monitoring is an essential part of care for critically ill patients. It provides more information on cardiovascular system function. There has been remarkable progress in the use of hemodynamic monitoring devices. However, the greater availability of these devices has not resulted in better survival rates, which would be expected if survival outcome correlated well with improved hemodynamic monitoring.

There are numerous reasons why hemodynamic monitoring might not improve survival outcome. In the human body, the cardiovascular system is just one of the systems responsible for oxygen delivery to the cells. Some of the hemodynamic monitors may help build a composite picture of how adequately the cardiovascular system is carrying out its task in the process, whereas others provide only those details (about the cardiovascular system) that may not have any bearing on the oxygen delivery process and so might not influence the outcome.

2. Physiological correlation between hemodynamic monitoring and outcome

2.1. Matching oxygen supply to oxygen demand

The survival of a patient depends on his or her receiving adequate oxygen delivery to all tissue beds at all times. This is possible only if there is an adequate flow of blood carrying enough oxygen in adequate amounts of hemoglobin. The ultimate in monitoring that will provide 100% sensitivity to survival outcome will require the care provider to monitor oxygen delivery to all the tissue beds at all times when the patient’s life is possibly under threat. Even if we have some details of the flow in the microcirculation, the actual amount of oxygen a cell receives still depends on its diffusing in adequate amounts from the capillary all the way to the mitochondria where it performs the most important task of ATP production with energy metabolism.

While we cannot monitor the oxygen delivery to all tissue beds, we do have the means to determine the composite uptake of oxygen by all the tissue beds. Mixed venous oxygen saturation gives us an idea of this uptake. The lower the oxygen saturation in the mixed venous blood, the higher the global uptake of oxygen has been, provided the flow and oxygen delivery to the tissues are constant. We know that while under normal circumstances this may be so, in a critically ill patient, the latter two parameters are...
never constant. Survival thus depends on matching the oxygen supply with its uptake in the patient. However, Gomersall et al. in an attempt to resuscitate critically ill patients by improving their gastric tonometry as an excellent studies that show some correlation of gastric tonometry with survival outcome. Again, in a hemodynamically unstable patient, this may affect. In a hemodynamically unstable patient, this may not be so, although a rising trend in the lactate level may be a useful indicator of poor tissue oxygenation.

2.2. Is redistribution of blood flow a possible indicator of poor oxygen supply?

Not all tissue beds behave the same during life threats. In the case of failed oxygen delivery, the gut is the first organ to sustain inadequate tissue oxygenation due to the redistribution of blood flow to more important tissue beds, especially those of the brain and the heart. Inadequate gut oxygenation therefore serves as an early warning system of tissue bed compromise, and it is possible to monitor this with gastrointestinal tonometry. There are some excellent studies that show some correlation of gastric tonometry with survival. However, Comersall et al. in an attempt to resuscitate critically ill patients by improving their gastric tonometry value failed to improve their survival outcome.

2.3. Recognizing the premier role of the cardiovascular system

The most important role of the cardiovascular system is to provide the blood flow required to carry oxygen to the tissues. This role of the cardiovascular system was recognized by the German physiologist Pfleger more than a 100 years ago. In order to perform this function, the cardiovascular system essentially houses a pump with a conduit or a network of vessels. This network can further be divided into its distributive (aorta and arteries), resistive (arterioles), exchange (capillaries), and capacitance (veins) roles in order to play the vital function of sustaining life.

2.4. Recognizing the setup of the cardiovascular system to play the role of oxygen delivery

Current hemodynamic monitoring allows us to scrutinize the various parts of the cardiovascular system, be it the pump, the distributive, the resistive, the exchange, or the capacitance part of the system. While details of the various parts may serve us well to alert where the deficit in tissue blood flow may be, most care providers are still not cognizant of the fact that the cardiovascular system is only one of the many systems responsible for delivering oxygen to the tissues. Together with the integrity of the cardiovascular system, the integrity of the airway, the breathing processes, the hemoglobin level, and the health of the tissue bed ultimately play their essential roles in sustaining life.

For the pump to work effectively, the electrical activity that precedes the contractility of the pump must be sinus rhythmic. The pump itself must receive adequate oxygenation via its own coronary blood vessels. There must also be enough blood in the chambers, especially the left ventricle, for an effective output to create the flow to all the tissue beds. All these parameters can be monitored for normacy and adequacy. Proper functioning of the cardiovascular system at the pump, the distributive, the resistive, and at the capacitance level does provide adequate oxygenation for tissues but may not totally guarantee the most important variable that affects the outcome—tissue oxygenation to all beds. This is where the crux of the problem lies. It is the basis for the lesser correlation with survival outcome.

When the oxygen demand increases in most tissue beds, it is met with increased supply of blood flow and thereby increased oxygen supply. This ability to meet the demands of the tissue beds is the hallmark of a healthy cardiovascular system. Challenging the cardiovascular system to determine the reserve function or to determine its global capability to meet the oxygen need of the cells provides us an idea of the level of function of the system. Hemodynamic monitoring along this direction has some degree of correlation with survival outcome. The limitation, however, is still the ability to measure only global capability instead of capacity in individual tissue beds. Certain tissue beds are more important than others and failure in oxygen delivery to these tissue beds can affect the survival outcome. The brain oxygen delivery is one of clear example of such.

3. Practical issues affecting hemodynamic monitoring and outcome

3.1. Limited technology to measure tissue oxygenation

Our inability to determine and ultimately control oxygen delivery to all tissue beds at all times severely hampers our ability to use hemodynamic monitoring to impact survival outcome. We are currently lack technology that will allow us to monitor oxygenation of all tissue beds. The closest we have got thus far with monitoring at this level is the use of near-infrared spectroscopy.

3.2. Early therapy to reduce damage

In order to impact survival, hemodynamic monitoring must be able to provide early warnings to allow care providers to immediately act to rectify the problem, because inadequate oxygen delivery is certain to cause damage. Several hemodynamic studies have shown that if the care is improved early, the outcome can be dramatically improved. Most patients come to care providers when their life threats are severe. They have already passed through a series of providers who have failed to recognize the extent of tissue damage over time. Even if extensive hemodynamic monitoring is provided, it may be too late to influence the outcome. Rivers et al. with their Early Goal Directed Therapy Collaborative Group managed to prove that patients whose early care included improved oxygen delivery would have a better chance of survival. Similarly, Shoemaker et al. by monitoring early hemodynamic deficits in their patients admitted into the emergency unit, were able to predict the survival of their patients. The survivors had lower deficits in terms of cardiac index and arterial hemoglobin concentration and better tissue oxygen perfusion. Both these studies deliberately selected to focus on the parameters that contributed effectively and collectively to tissue oxygenation, and hence these studies were able to show a predictable correlation between hemodynamic monitoring and survival outcome.

3.3. Hemodynamic monitoring parameters that do not affect oxygen delivery

Hemodynamic monitoring that yields physiologic data that do not influence oxygen delivery have little impact on survival. A good example would be the use of the pulmonary artery catheter, which could produce a wealth of physiologic data to help understand the physiology of the cardiovascular system but which has minimal impact in terms of survival benefit. Even though we can comprehend the mixed venous oxygen saturation from a pulmonary artery catheter, it does not provide information on oxygen delivery to individual tissue beds, and so it is a device that cannot impact survival.
3.4. Functional hemodynamic monitoring may be a useful tool

Hemodynamic monitoring in itself cannot impact survival. Outcome\textsuperscript{23–25} is more closely related to therapeutic measures that should rightly be instituted to improve survival with the hemodynamic details that monitoring provides. A new trend in monitoring—functional hemodynamic monitoring\textsuperscript{2,3}—with emphasis on how the parameters (e.g., with preload responsiveness) change with treatment strategies holds promise. Failure to institute the correct therapeutic measure\textsuperscript{2,3} by care providers may limit\textsuperscript{2,3} the correlation between hemodynamic monitoring and outcome. Care providers must understand how the hemodynamic parameters impact survival so that they may make a right choice in using these parameters to guide therapeutic measures in patient care.\textsuperscript{28}

3.5. Implications of paradigm shift from invasive monitoring to noninvasive monitoring

While attempts are made to determine the impact of hemodynamic monitoring on survival, it is important to remember that hemodynamic monitoring per se, especially invasive monitoring, can affect survival. There is a paradigm shift to using less invasive devices to reduce injury they bring about, but hemodynamic data from less invasive devices must first be validated\textsuperscript{27,28} against gold standards, which are usually obtained from more invasive instrumentation.

4. Monitoring pump function

4.1. Implications of monitoring pump function

Most monitors are designed to focus on surveying the ability of the heart pump to produce the output that the body requires. Unfortunately, the global cardiac output does not tell us the partitional flow\textsuperscript{29–31} to each individual organ or tissue. Even if the global output is normal, it does not guarantee each individual organ would receive what it requires. For example, in life-threatening hemorrhage, monitoring the function of the pump will not tell us much about what tissue beds are or may be compromised.\textsuperscript{10}

4.2. Low pump output is a good correlate of mortality

When the cardiac output is low,\textsuperscript{32} it can offer a high predictive value for mortality. The definition\textsuperscript{33} of normal is also arbitrary. It is only when the output is able to meet the demands of bodily energy requirement in all states can we say that the output of the heart is normal.

It is therefore not surprising that studies relative to cardiac monitoring could not show significant or close correlation of cardiac output with survival in all situations. Monitoring cardiac output reserve provides more details about the coping ability of the heart under stress and would show a better correlation between monitoring and outcome. Lang et al\textsuperscript{35} in measuring global output in response to exercise found it to be a good predictor of outcome in patients with chronic heart failure. His team was able to show the relationship between peak cardiac output and outcome in terms of death, urgent need of heart transplant, or the need of left ventricular assist device implantation in a series of patients with cardiac failure.

4.3. Pulmonary artery catheter is a good monitor of the pump

The pulmonary artery catheterization\textsuperscript{2,3} remains to date the gold standard for the monitoring of the heart pump, as it gives the most accurate measurement compared to other noninvasive hemodynamic monitors. While most of the noninvasive hemodynamic monitors of the pump have not been scrutinized for the correlation between monitoring and survival, it can be extrapolated that it is unlikely to show its outcome correlate with survival as the pulmonary artery catheter\textsuperscript{2-3} has dominated as the mainstay for monitoring the pump function for almost 40 years.

5. Monitoring of the distributive portion of the system

5.1. Absence of a good continuous organ flow monitor

Individual organ flow does not lend itself to continuous hemodynamic monitoring with present day technology. Its correlation with invasive techniques is poor. Bishop et al,\textsuperscript{36} in their study on the measurement of mid-cerebral artery blood flow velocity, found that this could not be used as a substitute for measurement of cerebral blood flow. At best, we can estimates\textsuperscript{14,37} the flow from other more easily available obtainable parameters.

5.2. Low organ blood flow is a good correlate of mortality

Even if the technology for the measurement of organ flow becomes a reality, it may not prove itself to be of good prognostic value. It must be understood that decreased flow may limit oxygen delivery to the organ but normal flow will not guarantee normal oxygen delivery to the organ,\textsuperscript{29–31} as cellular survival and ultimately patient survival are functions of the hemoglobin level and oxygen saturation along with local microcirculation variables, besides gross organ flow. Bouma et al\textsuperscript{36} have shown that even normal or high cerebral blood flow would not be predictive of favorable short-term outcome, but decreased cerebral blood flow leading to ischemia could be significantly associated with early mortality.

5.3. Poor correlation of blood pressure and flow

Blood pressure monitoring is one of the most accessible hemodynamic monitoring parameters for all patients. It is used as a substitute for flow because flow is proportional to blood pressure. However, as with cardiac output monitoring, adequate blood pressure does not ensure good flow to all tissue beds. Hypotension is, however, a good marker of poor survival outcome\textsuperscript{37,38} and in critically ill patients it can predict hospital mortality.

6. Monitoring of the resistive portion of the system

Vascular resistance monitoring is possible using a pulmonary artery catheter. The systemic vascular resistance and pulmonary vascular resistance can be determined. The state of reactivity\textsuperscript{19,40} of the systemic and the pulmonary resistance of the cardiovascular system can be used to predict survival outcome in patients with septicemia and with pulmonary hypertension, respectively. The limitation, however, is that it does offer continuous values.

7. Monitoring of the exchange portion of the system

7.1. Monitoring the microcirculation

The exchange portion of the cardiovascular system has been recognized as the most important area for monitoring since the advent of the last century. Pflueger\textsuperscript{13} has stated that all other portions of the cardiovascular system are of secondary importance and monitoring these parameters would be monitoring things that are incidental and subordinate. We are now seeing technology catching up with what is recognized as important but might be
provide better results than others. If oxygen delivery is measured, a better correlation between hemodynamic monitoring and outcome can become possible. With continuous improvements in technology, we may soon be able to measure the status of oxygen delivery at the cellular level. We may then be able to see the ultimate correlation of hemodynamic monitoring with outcome.

References