17 Hemodynamic Monitoring in Liver Transplantation

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Over the last five decades, Liver Transplantation (LT) surgical technique, anesthetic management and graft, and patient survival have undergone significant improvement. Despite these improvements, the intraoperative management of the patient undergoing LT remains challenging and is often accompanied by hemodynamic instability [1]. The pathophysiology of cirrhotic liver disease results in systemic vasodilation, altered circulating and total body volume status, and may be complicated by other organ system dysfunction [2]. This level of hemodynamic instability requires the use of a variety of hemodynamic monitors.

Liver transplant itself can be divided into three distinct phases: the pre-anhepatic phase, the anhepatic phase, and the neohepatic phase. Each phase has its own distinctive hemodynamic challenges [3, 4].

The pre-anhepatic phase is the dissection phase and is marked by significant changes in preload from large volume ascites drainage and acute and occasionally large volume blood loss, in addition to procedurally necessary manipulation of the liver and the vena cava.

During the anhepatic phase, the portal vein and inferior vena cava (IVC) are clamped and may result in decreased cardiac output (CO) by up to 50% under total venous occlusion (TVO) technique. This decrease is less dramatic under "piggyback" technique when the IVC is only partially occluded. Other forms of liver isolation which decrease blood loss include portocaval shunt and venovenous bypass. The technique for liver isolation is center dependent and patient specific [1, 5].

The neohepatic stage is when the newly implanted liver is reperfused and connected to the systemic circulation. This phase is marked by hemodynamic changes due to rapid return of blood from a previously obstructed portal system and the returned blood tends to be cold, acidotic, hyperkalemic, and contains a variety of inflammatory and vasoactive mediators [3, 5].

This results in transient but often significant decrease in myocardial contractility, systemic vascular resistance (SVR), chronotropy, and possible rise in pulmonary pressure.

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17.1 Blood Pressure

Given the potential for rapid changes in hemodynamics, invasive blood pressure (BP) monitoring is the standard for patients undergoing LT [1, 6]. The number and location of these lines vary by individual preference and center protocols. Cannulation of the radial artery provides safe and reliable blood pressure monitoring in nearly all patients. However, monitoring at a distal site, while convenient, does come with limitations. In certain situations, such as when high-dose vasopressors are being administered or when patients are in circulatory shock, the systolic pressures measured at the radial site are less reliable, and measurement of central arterial pressure via the femoral artery may provide more consistent pressure monitoring. However, even with this discrepancy, the mean arterial pressure tends to be consistent between the two sites [6, 7].

Risks of arterial cannulation for blood pressure monitoring include arterial or venous injury, bleeding, and nerve damage. While these risks are not theoretically different between femoral and peripheral sites, the femoral site cannot be visualized or easily evaluated during the procedure, and problems such as vascular bleeding may not be readily apparent. Specific situations may require more central cannulation despite the slightly higher risks of cannulating the femoral artery in select patients. Cannulation of the axillary or brachial artery can be considered, as well. Historically, there has been concern that the risk of nerve injury and ischemic injury may be higher with more proximal upper extremity cannulation, although recent data suggests that both are safe alternatives [8, 9]. Our observation over the past three decades has shown consistent discrepancies in radial and central pressures (systolic, diastolic, and mean) especially right after reperfusion and with the use of high-dose vasopressors. Extreme vasodilatory state which decreases distal pressure disproportionately to central pressure may be the cause of the variance post-reperfusion although none of the studies have consistently demonstrated this [10, 11]. Interestingly, one study showed that noninvasive BP measurement in the upper extremity more closely reflected central pressures than the radial invasive pressure, presumably due to the proximal location of the cuff [12].

In addition to the hemodynamic monitoring provided by arterial lines, the ability to measure arterial blood for gas exchange and metabolic demand is absolutely necessary for the safe performance of liver transplantation, given the potential risk of profound acid-base and electrolyte derangement.

17.2 Central Venous Pressure

Central venous access and measurement of central volume status via a catheter placed in the superior vena cava is standard practice during LT, although its utility in predicting such is often called into question.

The ideal use of CVP appears to be as a practical measure of volume status, where high values suggest volume adequacy or overload, and low values hypovolemia or underfilling. Unfortunately, in nearly all clinical scenarios, CVP as a variable only poorly reflects stroke volume and cardiac output, which are the clinically significant variables of concern. In cirrhotic patients with hyperdynamic circulations, some degree of portopulmonary hypertension, and concomitant ventricular hypertrophy and cardiomyopathy, the reliability of CVP is even more questionable. Additionally, studies of the impact of CVP in non-cirrhotic patients should not necessarily be expected to accurately reflect the altered physiology that occurs during LT.

Increased CVP has been implicated as a risk factor for complications during liver resection [13]. Maintenance of lower CVP during liver resection surgery has been associated with reduced blood loss, transfusion, risk of postoperative fluid overload, and secondary complications, such as pulmonary and gastrointestinal edema [13–15]. Reduced CVP/right atrial pressure allows for passive reduction in IVC pressure, which helps drainage of the hepatic venous system, reduced tension on the liver and associated venous structures. This may directly impact surgical bleeding during dissection and postoperatively, but also may increase the risk of air embolism and hypotension as a result of low stroke volume.

In patients with significant portal hypertension, the portomesenteric vasculature is already under pressure, and maintaining low CVP will theoretically help reduce this.

However, studies and expert opinion are mixed with regard to the actual benefit of low CVP in the LT patient, as most studies have excluded these patients in favor of those undergoing liver resection. In addition, use of artificial means to lower this number, such as systemic vasodilators and phlebotomy, may increase other risks of end-organ hypoperfusion. Thus, the accuracy and utility of the actual number remains unclear, and, ultimately, trends in CVP during the surgical procedure may be of most value [16, 17].

17.3 Invasive Cardiac Output Monitoring

In addition to the ability to measure CVP and administer vasopressors and accomplish large volume resuscitation, the presence of a central venous catheter of adequate size (typically at least eight French) may provide a conduit for pulmonary artery catheterization. Data from a pulmonary artery catheter (PAC) can provide information on intracardiac filling pressures, pulmonary hypertension, or alterations in cardiac output (CO), which all may be useful, especially in the patient with preexisting cardiac dysfunction (Fig. 17.1). Hemodynamic derangements are to be expected during all phases of LT, and monitoring of CO using PAC may provide valuable

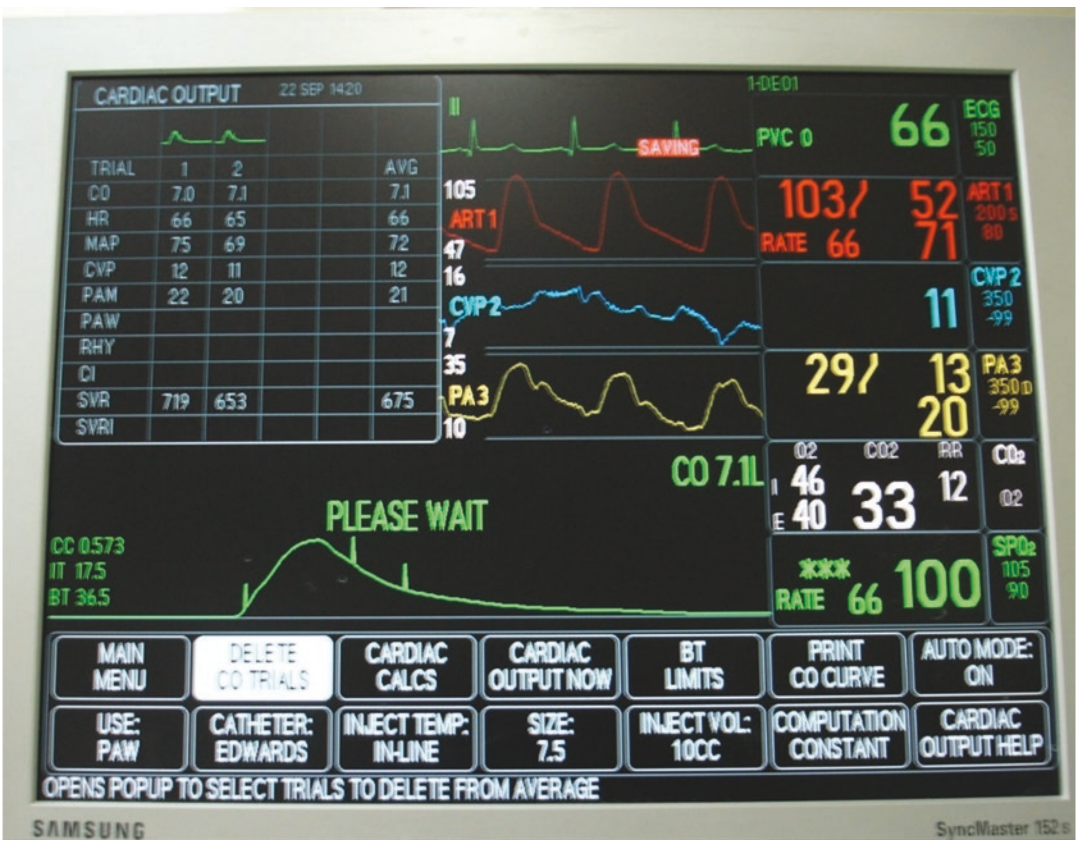

Fig. 17.1 Invasive hemodynamic monitor

real-time data to guide management in appropriate patients [4].

The PAC can deliver data on right-sided filling pressures directly, left-sided filling pressures indirectly, SVR, and CO, through either thermodilution or oximetric approaches. These data, when taken together, can provide numerical evidence of the cardiac function and quantify the degree of pulmonary hypertension, should any exist. In addition, changes in the measured pressures and calculated variables, such as end-diastolic volumes, can suggest altered central volume status. As referenced previously, there may be benefit in maintaining a normal or slightly reduced central volume status in LT patients, when appropriate, and PAC data can help with this guidance.

CO data can be assessed intermittently or continuously, depending on the choice of device. Typically, thermodilution CO is checked at intervals, while oximetric catheters report CO continuously through optical assessment of mixed venous oxygen, after an initial calibration.

The accuracy of the continuous cardiac output (CCO) monitors may decrease with time from calibration, while the use of intermittent monitors requires action on the part of the provider, which may not be feasible in times of high stress. Otherwise, these may be considered reasonably equitable approaches to measuring CO [18].

The presence of cirrhosis is typically associated with high CO states due to alterations in SVR and circulating volume status [19]. Altered systemic perfusion as measured by BP, acidosis, and urine output may not necessarily correlate with numerical changes in CO, especially if the absolute numbers remain above normal. Thus, the trend of CO and filling pressures may provide more useful data in many circumstances. In addition, cardiac contractility may be abnormal in cirrhotic patients even in the setting of normal or elevated CO.

The presence of cirrhotic cardiomyopathy may add complexity to the intraoperative management, as heart rate, CO, and BP can all be adversely impacted. Hypertrophic obstructive cardiomyopathy (HOCM) is also evident in some patients with cirrhotic liver disease, and management of these patients can present challenges during LT [20].

The PAC can provide many data points, which may help guide hemodynamic management of the LT patient. However, use of this monitor has become less common in LT over the years due to a slight increase in risk of the procedure, unclear benefit of the data provided, and desire for reduced resource utilization [21]. Of particular importance, CO data from PAC monitoring may be less precise in patients with hyperdynamic cardiac function, such as those with cirrhotic liver disease.

The PAC remains an important monitor in certain ESLD diagnoses such as portopulmonary hypertension and HOCM. The emergence of arterial pressure waveform analysis and increased use of transesophageal echocardiography have provided alternative monitoring strategies to conventional PAC [18].

17.4 Minimally Invasive Cardiac Output Monitoring

Arterial pressure-based CO calculations interpret the pulse pressure waveform presented by an arterial line. These have been validated to provide data comparable to that of the PAC, especially in prediction of CO response to fluid administration [22, 23]. Variations in pulse pressure, stroke volume, and systolic pressure are commonly used hemodynamic variables in the evaluation of CO in critically ill patients, although some difficulty exists when extrapolating these data to operative patients (Fig. 17.2).

Cardiac stroke volume can be interpreted from the arterial line waveform, which can be used to calculate CO. The fidelity of these devices is dependent on a properly functioning arterial line, and changes in patient positioning, manipulation of the abdominal structures, and altered vascular tone may all reduce the accuracy of the information gathered in this manner.

As referenced previously, peripheral arterial line hemodynamic measurements, such as those from radial arterial lines, may be impaired in

Fig. 17.2 Minimally invasive cardiac output monitor - VIgileo/ FloTrac and LiDCO

patients with high vasopressor requirement or those in shock, and in situations such as this, stroke volume calculations are likely to be less accurate.

Ultimately, the CO data generated from these devices are not as accurate as thermodilution methods using PAC, and in cases where CO monitoring is imperative, these devices should not be used as a substitute [23–25]. Direct measurement via thermodilution through a PAC remains the gold standard for measurement of CO.

17.5 Transesophageal Echocardiography

Transesophageal echocardiography (TEE) is able to provide real-time, dynamic, information about right and left heart systolic and diastolic function, volume status, regional wall motion as well as valvular function [26–28]. Intraoperative TEE has also been valuable in detecting conditions like cirrhotic or Takotsubo cardiomyopathy, HOCM, pulmonary hypertension, intracardiac air or thromboembolic events, and pericardial tamponade.

Use of TEE during LT is increasing, as it is seen as both more accurate and less invasive than other monitors of cardiac function, such as the PAC [29].

In a multicenter study of 244 patients undergoing LT, stroke volume index determined by TEE more strongly corelated with right ventricular end-diastolic volume index than CVP or PAOP [30]. CVP is also an unreliable indicator of stroke volume and intravascular volume [30].

Coronary artery disease (CAD) is not uncommon in patients undergoing LT. TEE has been shown to be more sensitive in detecting ischemia based on regional wall motion abnormalities as compared to other monitors including PAC [31].

Intracardiac thromboemboli may arise in association with caval manipulation, coagulopathy, and resuscitation, and TEE may provide evidence prior to catastrophic complication. The presence of thromboemboli is likely underappreciated, as one prospective study discovered 44% of patients with microemboli and 27% with larger emboli [32]. While smaller emboli are typically handled well by the pulmonary circulation, right ventricular dysfunction, failure and cardiovascular collapse can occur with larger ones. TEE provides real-time monitoring of the intracardiac status and is very useful in visualizing intracardiac thrombi, as well as "pre-thrombotic" characteristics such as microemboli and "smoke," suggestive of lower-flow states.

Paradoxical air embolus is a concern in liver transplant surgery. Patent foramen ovale (PFO), which predisposes to right-to-left intracardiac shunting, should be diagnosed by preoperative echocardiography, but these can be missed, or may not be evident with normal right-sided pressures. In addition, patients with cirrhosis often have a high degree of intrapulmonary shunting. This commonly exacerbates hypoxemia in these patients, but in rare cases, entrained venous air and microdebris can cross into the systemic circulation, with subsequent embolization to the brain, other organs, and extremities [33, 34]. Use of TEE in LT can alert the anesthesiologist to the presence of this air or debris in the cardiac chambers, even without hemodynamic changes, where standard monitoring is likely to miss this until manifested as hemodynamics change.

Placement and manipulation of a TEE probe is relatively simple in skilled hands, but patients with cirrhotic liver disease are at increased risk of esophageal pathology such as varices and stricture, and the presence and severity of these should be assessed prior to probe placement. Active bleeding and known esophageal pathology are two of the more common absolute contraindications to TEE. Risk of complication, such as major bleeding, is low [35] when used in liver transplant patients, even those with high MELD [36]. We recommend that the ability to rapidly tamponade a rupture gastric or esophageal varix be available for these patients, especially if TEE is used. Risks and benefits should be weighed prior to planned TEE placement, and it is perhaps reasonable to consider TEE as a focused therapy for a specific condition, rather than a monitor to be used in all liver transplant patients [37].

Key Points

- Proper hemodynamic monitoring is imperative in the management of the liver transplant recipient.
- Arterial blood pressure should be measured directly. The site chosen should balance the need for the reliability of proximal measurement and the complication risk of the site chosen.
- Central venous pressure monitoring is recommended, and following trends of this value may provide evidence of shifts in circulating volume status.
- In cases where precise cardiac output measurement is desired, use of the pulmonary artery catheter is recommended. In some circumstances, less invasive devices (LidCO, PicCO, etc.) may provide similar information based upon arterial waveform analysis.
- Transesophageal echocardiography is recommended as a tool for assessment of dynamic cardiac function, especially during complicated liver transplant cases. Placement and interpretation should only be undertaken by experienced providers.

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