INTRAOPERATIVE TRANSESOPHAGEAL ECHOCARDIOGRAPHY AND ANESTHETIC CONSIDERATIONS IN PATIENTS WITH VENTRICULAR ASSIST DEVICES

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Summary

A ventricular assist device (VAD) is inserted to provide mechanical circulatory support. A VAD can rest the myocardium and allow it to recover from stunning or hibernation, while maintaining vital organ perfusion (*bridge-to-recovery*). If myocardial recovery cannot occur, the goal is to support the patient to transplantation (*bridge-to-transplantation*), or, if the patient is not a transplant candidate, to enhance the quality of life for a limited period of time (*destination therapy*).

Perioperative transesophageal echocardiography is a major component of patient management, and it is important for surgical and anesthetic decision-making. In addition to the standard examination, device-specific pre-, intra-, and postoperative considerations are essential to the echocardiographic evaluation. These include: (a) the pre-VAD insertion examination of the heart and large vessels, in order to exclude significant aortic regurgitation, tricuspid regurgitation, mitral stenosis, patent foramen ovale or other cardiac abnormality that could lead to right-to-left shunt after the left VAD placement, intracardiac thrombi, ventricular scars, pulmonic regurgitation, pulmonary hypertension, pulmonary embolism and atherosclerotic disease in the ascending aorta; and to assess the right ventricular function; and (b) the post-VAD insertion examination of the device and reassessment of the heart and large vessels. The examination of the device aims to confirm the completeness of the device and heart deairing, cannulas alignment and patency, and the competency of the device valves using two-dimensional, and color, continuous and pulsed wave Doppler modalities. The goal of the heart examination after the implantation should be to exclude the aortic regurgitation or an uncovered right-

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to-left shunt, and to assess the right ventricular function, the left ventricular unloading, and the effect of the device settings on the global heart function.

Keywords: transesophageal echocardiography; ventricular assist device; right-to-left shunt; cardiopulmonary bypass.

INTRODUCTION

Over the years, the ventricular assist device (VAD) therapy has become an increasing option for patients with end-stage heart failure. High implantation costs, as well as long postoperative length of stay in debilitated patients' cases, make the VAD therapy [1-4] complicated.

In the multidisciplinary approach, the cardiac surgeons and the heart failure team evaluate potential VAD candidates together, starting immediately after the admission to hospital, to identify the optimal timing for the VAD implantation. Special attention is paid to not delaying the VAD implantation as to prevent the end-organ dysfunction, such as renal failure, hepatic failure and intubation.

VADs are used when pharmacological manipulations and intraaortic balloon pump counterpulsation fail to improve the cardiogenic shock or less severe low-output states that are worsening. In general, VADs are pumps that collect blood returning to the heart and eject it downstream of the failing ventricle.

Typically, for the left ventricular support, blood is drained from the left atrium or the left ventricular apex to the pump, and returned to the ascending aorta. For the right ventricular (RV) support, blood is drained from the right atrium or the RV to the pump and returned to the main pulmonary artery. The goal is either to decompress the acutely ischemic and failing ventricle (thereby reducing its oxygen demand), so it can recover, or to provide a long-term support for a chronically failing ventricle as either a bridge-to-transplantation or destination therapy.

As is the case with the diseased native heart, normal or slightly increased intravascular volume and normal or slightly decreased vascular resistance are necessary for the VADs to function optimally. Hypovolemia will delay the VAD filling with each pump cycle, which may decrease the overall pump output, leading thereby to hypotension.

Transesophageal echocardiography (TEE)

Transesophageal echocardiography (TEE) is an important tool in the perioperative management of patients undergoing VAD implantation. TEE has been shown to provide critical information on the diagnosis of preinsertion abnormalities, and the evaluation of postinsertion function [5,6].

Fig. 1: Mid-esophageal two-chamber view, showing dilated overloaded left ventricle in a patient with dilated cardiomyopathy.

The echocardiographic assessment of patients undergoing the VAD insertion involves aspects pertaining both to a general echocardiographic examination and to specific considerations associated with the VAD. As in most echocardiographic assessments, a comprenhensive examination is required [7-10].

DEFECTS CREATING INTRACARDIAC SHUNTS

Patent Foramen Ovale

The investigation of a Patent Foramen Ovale (PFO) should always be performed before and after cardiopulmonary bypass (CPB) for the implantation of a VAD. Since a PFO is common (27,3 % in one study) [11], meticulous care should be taken to identify its presence.

In the pre-CPB period, the examination of the interatrial septum of the patient with LV failure will often show a rightward deviation [12], indicative of an increased LA pressure surpassing the RA pressure. Because of this factor, the investigation of a PFO with color Doppler echocardiography may clearly show a left-to-right shunt. The TEE assessment for a PFO after the VAD insertion can be started early, while weaning from the CPB, and a PFO can be potentially detected even before complete separation. Early detection is important, as the presence of a PFO requires the return to a CPB for closure.

Other Septal Abnormalities

Traumatic atrial septal defects (fossa ovalis) can occur intraoperatively and also produce profound hypoxemia in the setting of increased right-to-left atrial pressure gradient with the LVAD support [13].

Finally, ventricular septal defects, particulary postinfarct, are a potential cause of significant shunting, before and after the VAD placement.

VALVULAR AND ASCENDING AORTIC DEFECTS

Aortic valve

Normal functioning of the LVAD during full support usually prevents the systolic opening of the native or prosthetic aortic valve, given the increase in the aortic-to-LV pressure gradient, due to the suction of the blood from the LV through the inflow cannula and its propulsion into the aorta through the outflow cannula.

Fig. 2: Mid-esophageal short (SAX) and long axis view (LAX), showing normal aortic valve in the preinsertion period.

Aortic Insufficiency

The diagnosis of significant pre- and postoperative Aortic Insufficiency (AI) is crucial in patients receiving an LVAD. The presence of AI reduces the forward flow produced by the LVAD, due to the regurgitation of the LVAD-supported flow into the LV cavity. Aortic competence should also be assessed during the CPB by intraoperative TEE, before the insertion of the LVAD [14], when transvalvular gradients are closer to those to be observed after the LVAD insertion. The identification of severe and, possibly, moderate AI should indicate the need for surgical correction [15].

In patients with no previous aortic insufficiency, the incidence of AI after the LVAD insertion is low [16], and it may become present months later [17, 18]. Mechanisms producing the post-LVAD AI include endocarditis [19], aortic dissection [20, 21], and aortic leaflet prolapse or perforation.

Aortic Stenosis

Preoperative Aortic Stenosis (AS) is usually not critical to LVAD recipients, since pulsatile devices typically generate full cardiac output and, thus, the systemic blood flow does not depend on antegrade flow through the aortic valve. In VADs that provide partial or variable support, such as axial flow devices, the intermittent opening of the aortic valve occurs and contributes to a global cardiac output. Consequently, patients with severe AS may not be good candidates for such devices.

Ascending Aorta

The ascending aorta should be examined to detect abnormalities before performing the end-to-side anastomosis of the outflow cannula. A mid-esophageal (ME) ascending aortic long-axis view should be used to locate and classify the structural abnormalities in the ascending aorta. The aortic arch and the descending aorta should be assessed with the same goal. Atheromata with thickness > 5 mm and/or protruding and/or mobile components are associated with an increased risk of cerebral embolic events during the cardiac surgery.

Tricuspid Regurgitation

Functional Tricuspid Regurgitation (TR) is a common finding in patients with heart failure. Adequate RV function is essential after an LVAD insertion to optimize the LVAD filling. The presence of significant postoperative TR can significantly contribute to the RV dysfunction and the development of a low output state. Given that LVAD insertion produces the unloading of the LV and a decrease in the PA pressure, it might be expected that TR would be reduced post-insertion. Some authors have found this true, but not others, who reported an acute worsening in TR after the LVAD insertion. The fact that an isolated implantation of an LVAD does not produce a consistent change in the degree of perioperative TR is likely associated with a combination of factors, including the leftward shift of the interventricular septum, produced by the LVAD; an increase in the PA pressure and the RV dysfunction due to the inflammatory response to surgery, CPB and blood transfusion; and an increase in preload to the RV due to an increased left-sided output, delivered by a functioning LVAD in lieu of the previously failing left heart. Leftward interventricular septal shift is more pronounced in LVAD patients, who are hypovolemic and have higher VADs flows.

Fig. 3: Massive tricuspid regurgitation after the LVAD insertion.

MITRAL VALVE

Mitral Regurgitation

Functional Mitral Regurgitation (MR) is a significant and common complication of end-stage heart failure and cardiomyopathy [22,23]. A central jet on the color Doppler image, which has been reported to be of at least moderate severity in 39 % of the patients in a retrospective study of patients with advanced systolic heart failure, characterizes this form of MR. The insertion of a LVAD leads to reduced LV size, an improved coaptation of the mitral valve leaflets and, ultimately, a decreased preexisting MR. The persistence of significant MR post-LVAD insertion may indicate inadequate LV decompression.

Mitral Stenosis

Mitral Stenosis (MS) is a rare finding in patients scheduled for an LVAD insertion. Significant MS restricts the filling of the LVAD, leading to low device output and, consequently, to low cardiac output. RV failure can also occur due to increased pulmonary vascular resistance (PVR).

Pulmonic Valve

Pulmonic valve lesions are relatively rare in patients receiving a VAD. Pulmonic insufficiency more than moderate would be an important finding in those patients.

In patients receiving only an LVAD, it would compromise the RV function through volume overload.

VENTRICULAR ASSESSMENT

Right Ventricle

The RV dysfunction is a well-recognized and serious condition that may occur in LVAD recipients. As the output of the native RV determines the preload of the LVAD [24], a decrease in RV function will translate into a reduction in the LVAD output. Reports suggest that at least 9-33 % of patients suffer severe RV failure after the LVAD insertion [25-30] and may require an RVAD. This decision is often needed when a CPB is discontinued, because the RVAD insertion should be performed early after the development of severe RV failure following LVAD implantation.

Left Ventricle

The evaluation of the LV function pre-LVAD insertion will show depressed function with either a dilated or normal size ventricle, depending on the cause of heart failure. The LV ejection fraction (LVEF) for LVAD insertion is typically <25-30 %. Significant diastolic dysfunction is also usually present and diagnosed with PW Doppler of the transmitral inflow, combined with PW Doppler of the pulmonary veins or with tissue Doppler. Severe LV dysfunction increases the risk of apical thrombus formation. Apical thrombus, when present, is often located near the inflow cannula insertion site. Thus, the preoperative interrogation of the LV for the presence of thrombus is an essential part of the echocardiographic examination.

THE ASSESSMENT OF VAD COMPONENTS

Cannula position

Inflow cannula. The inflow cannulas and their orientation within the RA, the LA or the ventricles can be visualized on two-dimension imaging. The inflow cannula to an LVAD may originate from the LA or the LV. The most common origin is the apex of the LV and, in this case, the cannula should be aligned with the LV inflow tract, i.e. with the mitral valve opening, and not abutting any wall.

Outflow cannula. The outflow cannula for an LVAD or an RVAD is visualized with two-dimensional imaging. A long axis view of the ascending aorta at the level of the right PA will usually show the outflow cannula anastomosis to the ascending aorta. The ascending aorta should also be checked for the presence of calcification, plaque, or dilation, which could modify the placement of the cannula.
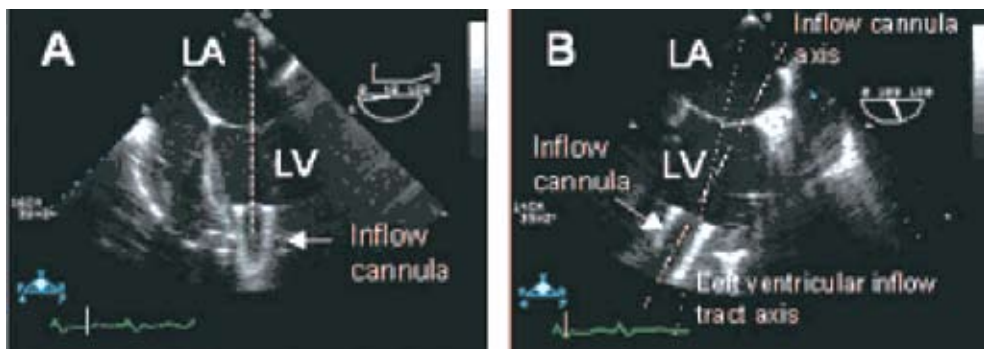
Fig. 4: The alignment of the left ventricular assist device (LVAD) inflow cannula, mid-esophageal four-chamber view (A). The ideal axial alignment will optimize blood flow to assist the device. A small angle is observed between axes for the two-chamber view (B).
LA = left atrium; LV = left ventricle.

Thromboemboli

The presence of intracavitary thrombi requires extra care during cannulation, as there is a risk of embolism. The incidence of thromboembolic complications after the LVAD support varies significantly in different reports between 5 % and 47 %. The use of TEE allows for the identification of mobile LV thrombi adjacent to the LVAD inflow cannula, and the LV outflow tract.

Anesthetic Considerations in Patients with Ventricular Assist Devices

In the end stage of cardiac failure, patients inevitably have mild to severe pulmonary hypertension and may be on chronic inodilator therapy with dobutamine
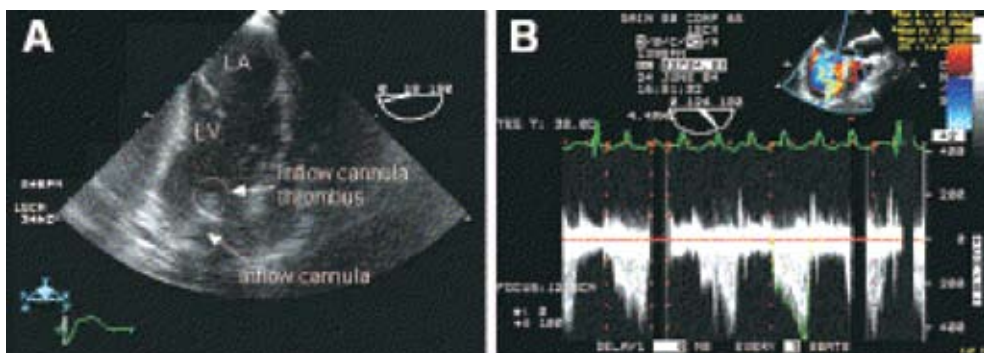

Fig. 5: (A) Echodense structure at the inlet of the inflow cannula compatible with a thrombus. The obstruction of the inflow cannula can produce an increase in the velocity at the inflow cannula (B). LA = left atrium; LV = left ventricle.

and/or milrinone; they furthermore suffer from substantial hepatic, renal and pulmonary insufficiency. Some may have an IABP in place and be already mechanically ventilated or on intermittent or continuous hemodialysis. Many of these patients are reops (prior coronary revascularization, valve surgery, AICD), and require therefore the anticipation of major bleeding and/or the incision of vital structures during opening, dissection and cannulation.

In anticipation of the potential for massive blood loss, large bore central venous access is obtained together with pulmonary artery catheterization. A rapid infusion blood-warming device is primed to ensure the ability to give fully warmed blood and blood products at the volumes of 250-1000 mL/min. Blood and blood products (e.g. 6 units of packed red blood cells, 6 units of fresh frozen plasma, 12 units of platelets) are readied in preparation for post-CPB coagulopathy. Early transfusion may reverse factor deficiency before vicious cycles (bleeding → DIC → bleeding) develop.

The anesthetic regimen should acknowledge the tenuous hemodynamic state and compromised drug elimination capacity of these patients; for example, cisatracurium should be used instead of vecuronium.

Aprotinin, a kallikrein and serine protease inhibitor, which has antifibrinolytic and platelet sparing effects on the CPB, may be used, as it has been proven to decrease the blood loss, the blood requirement and perioperative mortality. Some advocate priming the CPB circuit with fresh frozen plasma to decrease the dilution of clotting factors in patients with preoperative coagulopathy, and maintain the levels of antithrombin III, avoiding thereby consumptive coagulopathy.

Transesophageal echocardiography (TEE) is essential not only to monitor the LV filling and the RV function throughout the case, but also to exclude the presence of an atrial septal defect (ASD), the patent foramen ovale (PFO), aortic regurgitation or mitral stenosis. These lesions must be repaired prior to the separation from the CPB; with an ASD or a PFO, a right-to-left shunt may commence, as the left-sided filling pressures are decreased when the LVAD support begins.

Adequate LVAD output during the separation from the CPB requires aggressive volume loading, since the LVAD decompresses the LV and the left atrium. The RV dysfunction is treated with inodilator drugs (milrinone, dobutamine), whilst excessive systemic vasodilatation, causing systemic hypotension, is treated with norepinephrine and/or vasopressin. Severe pulmonary hypertension may induce an acute RV failure and responds well to inhaled nitric oxide, 10-20 ppm, which has markedly decreased the requirement for emergency placement of an RVAD to come off the CPB in the OR.

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Sažetak

Intraoperacijski TEE i anesteziološko liječenje bolesnika s mehaničkom potporom srca

Uređaj za mehaničku potporu srcu (eng. VAD) se ugrađuje radi pružanja mehaničke potpore srcu i cirkulaciji. Njime se osigurava oporavak miokarda nakon *stunninga* i *hibernacije,* i u isto vrijeme održava perfuzija vitalnih organa (eng. bridge-to-recovery). Ukoliko se miokard ne može oporaviti od oštećenja tada je cilj ovakve terapije pružiti potporu bolesniku do trenutka transplantacije srca (eng. bridge-to-transplantation), ili ukoliko bolesnik nije pogodan za transplantaciju, poboljšati mu kvalitetu života u ograničenom vremenu (*ciljna terapija*).

Perioperacijski TEE je glavna metoda u liječenju i nadziranju takvih bolesnika koja pruža brojne informacije i kirurgu i anesteziologu, olakšavajući pri tom donošenje važnih terapijskih odluka. Uz osnovni standardni pregled, za ehokardiografsku procjenu su važni i za uređaj specifični pre-, intra- i postoperacijski ehokardiografski pregled. To uključuje: (a) pregled srca i velikih krvnih žila prije postavljanja VAD uređaja, kako bi se isključila značajnija aortna regurgitacija, trikuspidna regurgitacija, mitralna stenoza, otvoreni foramen ovale i druge abnormalnosti koje bi mogle dovesti do D-L shunt-a nakon postavljanja VAD-a, stvaranja intrakardijalnih tromba, ventrikulskih ožiljaka, plućne regurgitacije i hipertenzije, plućne embolije i aterosklerotske bolesti u uzlaznoj aorti. Važno je i procijeniti funkciju desnog ventrikula, i (b) pregled uređaja nakon postavljanja VAD-a i ponovna procjena srca i velikih krvnih žila. Cilj pregleda uređaja je potvrditi ispravnost uređaja, izvršenog srčanog odzračivanja; potvrditi ispravan položaj kanila i njihovu prohodnost, kompetentnost valvula i to uporabom dvodimenzionalnog, obojenog, kontinuiranog i pulsnog doplera. Cilj pregleda srca nakon implantacije je isključiti aortnu regurgitaciju ili neprepoznati D-L shunt, i procijeniti funkciju desnog ventrikla, odterećenost lijevog ventrikla i općenito učinak različitih podešavanja uređaja na globalnu srčanu funkciju.

Ključne riječi: transezofagusna ehokardiografija; uređaj za mehaničku potporu; desno-lijevi shunt (D-L); izvantjelesni krvotok