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Review

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ECHOCARDIOGRAPHIC EVALUATION OF PATIENTS WITH HEART MATE II CONTINUOUS FLOW VENTRICULAR ASSIST DEVICE

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Summary

Echocardiography plays an important role in evaluating patients both before and after the implantation of mechanical circulatory support devices. It consists of a standard examination expanded to specific aspects of ventricular assist devices. The scope of examination varies according to the type of the device, the method of implantation and the localization of the inflow and outflow cannulas. This article is focused on the echocardiographic examination of patients undergoing the implantation of the HeartMate II (Thoratec) – a continuous-flow ventricular assist device. It provides a review of all the important parts of the examination, including the preoperative, the intraoperative and the postoperative examination. The utilization of transthoracic and transesophageal echocardiography is presented. The methods of diagnosing the malfunction of the device are also discussed. The author emphasizes that the assessment of a patient with a mechanical assist device is a complex and an interdisciplinary challenge, where echocardiography is crucial in the assessment of the patients with mechanical circulatory support devices.

Key words: echocardiography; ventricular assist device

The echocardiographic examination is crucial in assessing the diagnosis and monitoring of the clinical status of patients with heart failure. Its role is especially important in patients with advanced heart failure. The idea of using mechanical circulatory support has improved significantly in recent years. Ventricular assist devices (VAD) are used more and more often in the treatment of patients with end stage heart failure. Echocardiography plays an important role in assessing the patients treated with mechanical circulatory support devices.

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In general, the echocardiographic examination of the patient before and after VAD insertion consists of a standard examination expanded to specific aspects of VAD. The scope of examination varies according to the type of the device, the method of implantation and localization of the inflow and outflow cannulas. This article is focused on the echocardiographic examination of patients undergoing the implantation of the Heart Mate II (Thoratec) – a continuous flow ventricular assist device.

The use of echocardiographic examination concerns all phases of device implantation. It includes:

- Preoperative examination and qualification to VAD implantation (TTE, TEE);
- Perioperative examination (TEE);
- Early postoperative monitoring in the intensive care unit (TEE, TTE);
- Long-term follow-up (TTE, TEE).

To attain these goals, the echocardiographic examination should be focused on:

- Assessment of the left ventricle (LV);
- Assessment of the right ventricle (RV);
- Identification of intracardiac shunts;
- Assessment of the valves;
- Identification of intracardiac thrombi;
- Assessment of the aorta;

After device implantation:

- Deairing of the heart and the device;
- Assessment of the alignment of the inflow and outflow cannula;
- Left ventricular unloading;
- Right ventricular function;
- Assessment of the flow pattern in the inflow and outflow cannula;
- Reassessment of the aortic valve, intracardiac shunts and aortic dissection.

The assessment of the preoperative status of the patient should answer the following questions:

- Is the patient really a candidate for VAD implantation?
- What type of VAD device should be implanted according to the heart functional status?
- Are there concomitant diseases impeding device implantation present?

The evaluation of the pre-VAD patient is a multidisciplinary approach, where an echocardiographer should confirm myocardial dysfunction being the cause of the existing heart failure. Next, the assessments of the ventricular function and the

anatomical structure of the heart allow choosing the appropriate type of the device. The identification of coexisting pathologies permits an appropriate planning of operation scope.

The assessment of the left ventricle

The size of LV, wall thickness and diastolic function should be assessed. The evaluation of the insertion site in the apex of the left ventricle including wall thickness, the presence of scar and thrombi should be performed.

The assessment of the right ventricle

The assessment of the right ventricular function is a most important clinical problem, as the right heart failure occurs after LVAD implantation in up to 33 % of patients [1]. This is especially important in patients with axial flow pumps, while severe right ventricular failure requires the implantation of RVAD device, which nowadays means a pulsatile flow device. A few successful cases of right and left ventricular support with two axial flow pumps were reported lately. In patients with advanced heart failure, the severely impaired left ventricular function causes the decrease of the right ventricular preload. Under a decreased preload, the right ventricular function can be apparently preserved, yet under VAD support, the rapid increase of cardiac output causes an increase of preload of the right heart, and the right ventricle failure can become apparent despite the usually concomitant reduction of the right ventricular afterload. The right ventricular dysfunction is difficult to predict because of its multifactorial origin. The echocardiographic evaluation of the right ventricle is difficult because of its complex anatomical structure. There are no uniform, echocardiographic methods for the assessment of the right ventricle function. The semiquantitative evaluation includes the visual estimation of the RV size and contractility using 2D TTE and TEE images. The longitudinal function, defined as tricuspid annulus to RV apex motion, and free wall contractility are assessed.

The most often used quantitative parameters are as follows:

- Right ventricular end diastolic diameter – RVEDD (mm);
- Global right ventricular fractional area change – RV-FAC (%);
- Regional right ventricular fractional area change – RVOT fs (%);
- Maximum derivate of the right ventricular pressure – dp/dt max;
- Tricuspid annular plane systolic excursion – TAPSE (mm);
- Right ventricular systolic pressure – RVSP (mmHg);
- Pulmonary acceleration time – Acc (ms).

The grading of the RV dysfunction including both semiquantitative and quantitative methods of RV assessment was proposed (2). Grade I includes patients with moderately increased RVEDD, RV-FAC 30-35 %, RVOT fs 20-40 %, RVSP 30-50 mmHg, moderate to severe tricuspid insufficiency, Acc < 90 ms and TAPSE 10-15 mm. In this group of patients, RV failure after VAD implantation is less probable. Group II consists of patients with RV-FAC < 25 %, RVOT fs < 20 % and TAPSE < 10 mm. The systolic pressure in the RV is diminished and mild tricuspid insufficiency can be observed. In this group of patients, excessive pharmacological support is necessary; however, the right ventricular assist device implantation may be required. The third group consists of patients with evident RV dilatation (RVEDD > 80 mm) and dysfunction, who require RV mechanical support. The decision in most cases is difficult and is made in the operating theatre after the discontinuation of the cardiopulmonary bypass (CPB), or in the short time after the starting of the support of the left ventricle [2,3].

The identification of intracardiac shunts

The most common shunt observed is Patent Foramen Ovale (PFO); this shunt occurs in up to 27 % of patients [4]. The methods of examination do not differ from the standard examination; however, the examination of a patient with advanced heart failure requires several remarks. First and foremost, the LV dysfunction with elevated left-side pressures will unmask left to right shunt, which can be easily recognized with color Doppler (Fig. 1). In case of an increase in the right-side pressures, left to right shunt may not be visible despite the use of echocardiographic contrast and Valsalva maneuver. The latter must be used with caution in a patient with advanced heart failure. The assessment of the continuity of the interatrial septum should be repeated after the introduction of CPB and after starting the VAD device. Significant shunts must be closed at the time of operation. The exploration of other possible sites of intracardiac shunts should not be omitted.

The assessment of the valves

The evaluation of the aortic valve is a very important part of preoperative examination. Aortic insufficiency, when significant, can reduce the VAD forward flow. The assessment of the degree of regurgitation does not differ from standard examination. In patients with severe left ventricular dysfunction and elevated left ventricular and diastolic pressure, as well as diminished pressure in the aorta, the severity of aortic regurgitation can be underestimated. Repeated examination after introduction of CPB allows the estimation of the aortic valve function under increased pre-

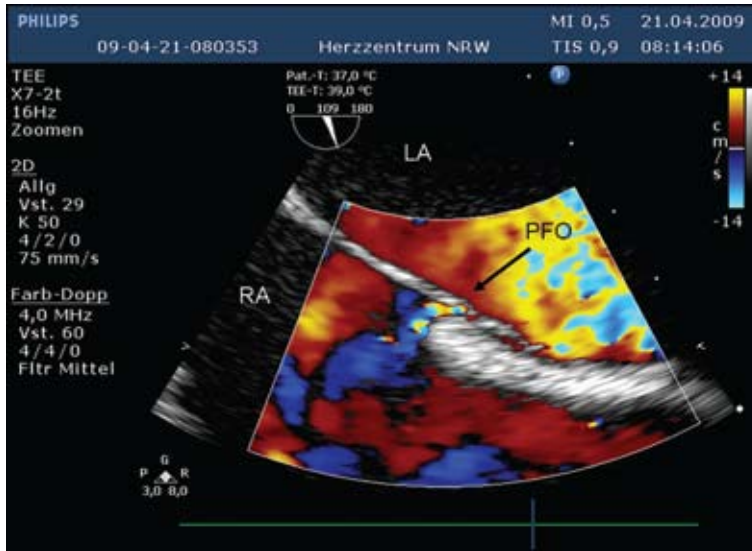


Fig. 1. 2-D and Color Doppler transesophageal echocardiographic examination. Patent Foramen Ovale with left to right shunt. LA – left atrium, RA – right atrium, PFO – Patent Foramen Ovale.

ssure. The inspection of the aortic valve should be repeated intraoperatively after starting the device following the implantation. The significant regurgitation requires surgical intervention and concomitant valve reconstruction, or the implantation of the bioprosthesis. The stenosis of the aortic valve, unless severe, does not require any additional intervention. The status of the aortic valve requires systematic evaluation during follow-up, because both regurgitation and stenosis can increase in time following VAD implantation. The tricuspid valve regurgitation is often observed in patients prior to VAD implantation. Its appropriate assessment is important, while the degree of tricuspid regurgitation can contribute to the right ventricular function after the implantation. The proper evaluation of the underlying mechanism (functional or organic) and a degree of regurgitation is crucial. The severe regurgitation requires surgical intervention. The degree of tricuspid regurgitation can change after LVAD implantation and depends upon many factors, such as right and left ventricular filling, and interventricular septum shift. Too excessive unloading of the left ventricle causes leftward shift of the interventricular septum and an increase in tricuspid regurgitation. The decrease in the pump speed causes an increase in the diameter of the left ventricle; the interventricular septum is moved to the right, and the tricuspid insufficiency diminishes. The mitral regurgitation is common in patients with heart failure, and although being frequently severe prior to the implantation, it decreases after unloading of the LV following VAD implantation. Persistent

high-grade mitral regurgitation may indicate an inadequate unloading of the left ventricle. Surgical intervention is uncommon. Mitral stenosis is rare; if significant, it requires surgical repair. Pulmonary valve regurgitation or stenosis, if significant, may impair right ventricular function. In those cases, surgical intervention is required [2,3].

The identification of intracardiac thrombi

Enlarged heart chambers, decreased global systolic function, regional wall motion abnormalities and atrial fibrillation contribute to the increased probability of thrombus formation. The most recent localizations are apex and left atrial appendage.

The assessment of the aorta

The echocardiographic examination of the ascending aorta allows identifying atherosclerotic changes in the aortic wall and choosing the proper site of distal anastomosis. The excessive atheromata are associated with an increased risk of thromboembolism. In case of aortic dissection, surgical intervention prior to VAD implantation is necessary.

Perioperative examination

The principle of the transesophageal echocardiographic examination during VAD insertion, before beginning of the CPB, does not differ from the preoperative examination. In cases in which TEE was not performed preoperatively, intraoperative TEE should confirm previous results, particularly those concerning intracardiac shunts and the presence of thrombi.

Inspection for presence of the air concerns both the heart and the device. The air is most frequently located in the apex of the left ventricle, in the left atrial appendage and in the left atrium near pulmonary veins. Both cannulas and the sites of anastomosis are also a potential source of air embolism.

The evaluation of the alignment of inflow and outflow cannulas should also be performed after chest closure. The inflow cannula should be directed toward the mitral valve and should not touch any wall (Fig. 2). The flow in the left ventricle and both cannulas can be estimated using Color Doppler and measured with both PW and CW Doppler. While assessing the inflow cannula, unidirectional and laminar flow without turbulence should be considered normal. PW measurements show a continuous pattern of flow with slight pulsatile increase in the flow velocity, synchronous with cardiac contraction (Fig. 3a, Fig. 3b). The continuous flow velocity signal from 0,6 to 1,2 m/s can be demonstrated. The maximal flow velocities of 1-2 m/s are considered normal [2,3,5]. The properly unloaded left ventricle has approximately

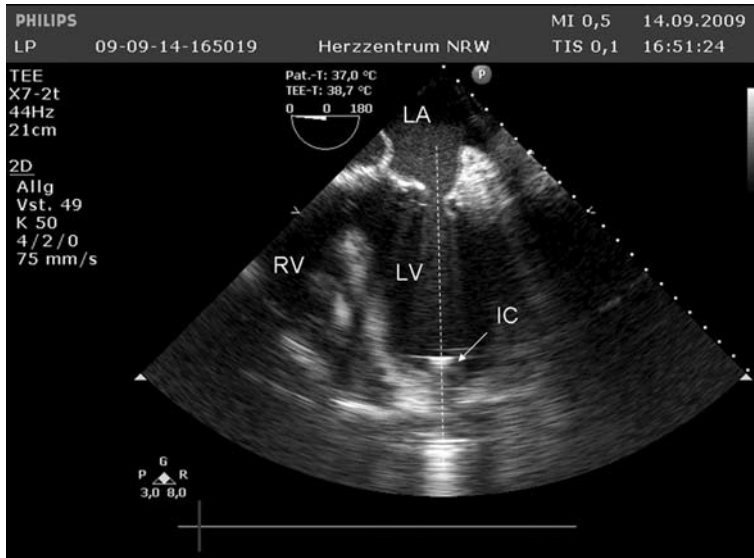


Fig. 2. 2-D transesophageal echocardiographic examination, 4 chamber view. The inflow cannula in the apex of the left ventricle. LA – left atrium, LV – left ventricle, RV – right ventricle, Arrow shows the inflow cannula – IC. Dashed line shows axis between inflow cannula and mitral valve.

normal diameter, the aortic valve is permanently closed (Fig. 4) and the interventricular septum is in the neutral position. Intermittent partial aortic valve opening is acceptable and should decrease the risk of thromboembolic complications. The function of the right ventricle should be carefully monitored after VAD is started. The methods of assessing its function are similar to preoperative evaluation.

Early postoperative monitoring in the intensive care unit

The evaluation of VAD function in the intensive care unit early after implantation is performed according to the clinical status of the patient, with special attention being paid to bleeding and possible tamponade. The standard echocardiographic examination including the assessment of all mentioned earlier parameters should always be performed.

The assessment of the ventricular assist device during a long-term follow-up

The echocardiographic examination is an important part of a patient's status assessment during follow-up. Transthoracic examination is sufficient in most un-

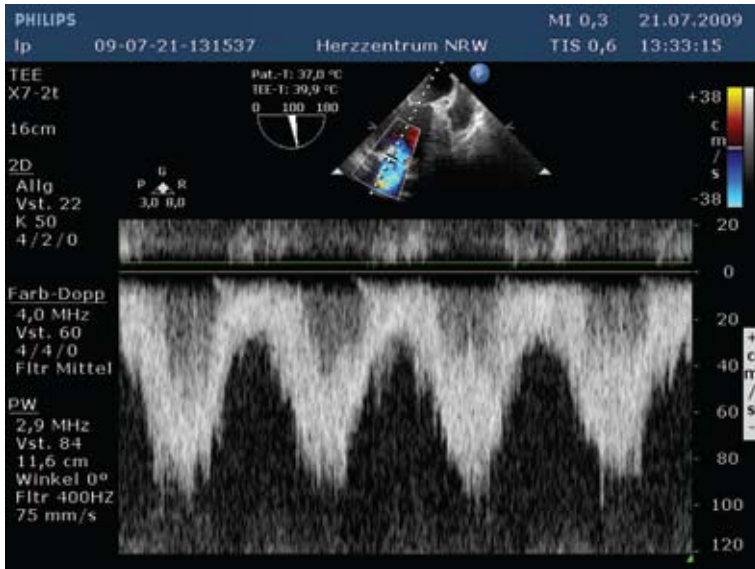


Fig. 3. PW and CW Doppler transesophageal echocardiographic examination. Flow velocity pattern across the inflow (a) and outflow cannula (b).

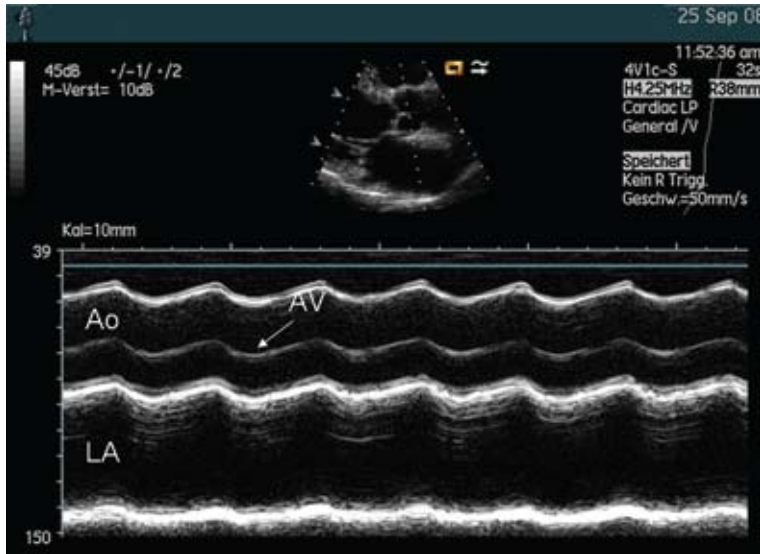


Fig. 4. M–Mode echocardiographic examination. AV remains closed both in systole and diastole. Ao – aorta ascendens, AV – aortic valve, LA – left atrium.

complicated cases. In special cases, transesophageal examination is necessary. The standard TTE examination should be performed including the cannulas alignment and the flow velocity pattern. The visualisation of the outflow cannula is often possible in the second right intercostal space (Fig. 5). Since the device flow is dependent on pre and afterload, as well as on the pump speed, the actual blood pressure and pump speed should be noted.

Ventricular assist device dysfunction

The continuous flow device malfunction is relatively seldom. In the group of 133 patients with the Heart Mate II device, pump replacement was necessary in 9 % of patients, but thrombosis was documented only in 5 cases (4 %). The breakage of the percutaneous lead was the main cause of malfunction [6]. As the direct evaluation of the pump is not possible with the use of echocardiography, the diagnosis of suspected pump thrombosis must be established indirectly, by the assessment of cannulas and ventricle function. Echocardiographic signs suggesting device malfunction include the dilatation of the left ventricle, a permanent opening of the aortic valve and interventricular septum shift to the right, suggesting the insufficient unloading of the left ventricle [7]. A lack of improvement after the adjustment of the pump speed suggests device dysfunction. The possible reasons for device malfunction include

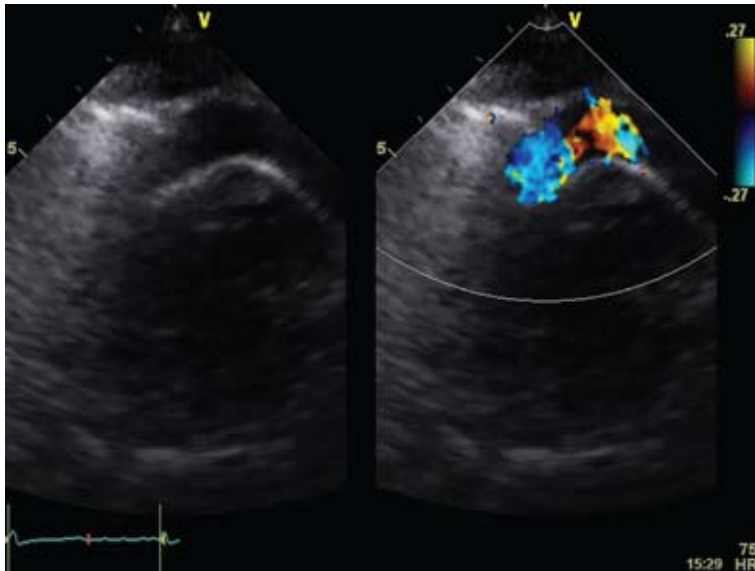


Fig. 5. 2-D and Color Doppler transthoracic echocardiographic examination, right parasternal view (second intercostal space). The outflow cannula with flow is visible.

inflow and outflow cannula obstruction, and flow obstruction inside the pump. Both transthoracic and transesophageal echocardiography can be useful methods of assessing VAD function.

Echocardiography is a powerful tool in assessing patients with mechanical circulatory support devices. However, one must remember that the assessment of a patient with a mechanical assist device is a complex, interdisciplinary challenge, and the echocardiographic examination should be taken into account only together with the analysis of the complete clinical data.

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Sažetak

Ehokardiografska procjena bolesnika s mehaničkom potporom srcu Heart Mate II

Ehokardiografija igra ključnu ulogu u kliničkoj prognozi pacijenta prije i poslije ugradnje uređaja za mehaničku potporu srcu i cirkulaciji. Ova metoda uključuje standardni pregled sa specifičnim pogledom na ventrikularni potporni uređaj. Područje pregleda ovisi o vrsti uređaja, metodi implantacije i smještaju ulazne i izlazne kanile. Ovaj članak opisuje ehokardiografski pregled pacijenta te što je sve potrebno sagledati prilikom preoperativnog, intraoperativnog i postoperativnog pregleda. Prikazan je način upotrebe transtorakalnog i transezofagijskog ehokardiografa. Opisuju se i metode dijagnosticiranja nepravilnog rada uređaja za mehaničku potporu. Autor naglašava kompleksnost dijagnostike pacijenata s ugrađenom mehaničkom potporom srcu i cirkulaciji te prikazuje ehokardiografiju kao neophodnu dijagnostičku metodu kod ovih pacijenata.

Ključne riječi: ehokardiografija; mehanička potpora srcu

