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Review

Long-term assist device patients admitted to ICU: Tips and pitfalls

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ABSTRACT

Left ventricular assist device (LVAD) therapy is well-established in the treatment of end-stage cardiac failure. Indications are bridge to transplant (BTT), bridge to candidacy (BTC), bridge to recovery (BTR), and destination therapy (DT). The durability and adverse event (AE) rate of LVADs have improved over the years. However, due to donor shortage, the duration of support in the BTT population has increased tremendously; similarly, DT patients are on the device for a long time. Consequently, the number of readmissions of long-term LVAD patients has increased. In cases of severe AEs, intensive care unit (ICU) treatment can be necessary. Infectious complications are the most common AE. Furthermore, embolic or hemorrhagic strokes can occur due to foreign surfaces, acquired von Willebrand syndrome, and anticoagulation treatment. Another consequence of the coagulative status, in combination with the continuous flow, are gastrointestinal bleeding events. Moreover, in most patients, an isolated LVAD is implanted, and this involves the risk of late right heart failure. Adjustment of pump speed and optimization of the volume status can help solve this issue. Malignant arrhythmias, pre-existing or *de novo* after LVAD implantation, can be a life-threatening AE. Antiarrhythmic medical therapy or ablation are potential treatment options. As for specific LVADs, the Medtronic HeartWare™ ventricular assist device (HVAD) is not manufactured and distributed currently; however, 4000 patients are still on the device. Pump thrombosis can occur, wherein thrombolytic therapy is the first-line treatment option. Additionally, the HVAD can fail to restart after controller exchange due to technical issues, and precautions must be taken. The Momentum 3 trial showed superior survival without pump exchange or disabling stroke in patients treated with the HeartMate 3® (HM3; Abbott, Abbott Park, IL, USA) device in comparison to the HeartMate II (HMII). However, in a few cases, a twisted graft or bio debris formation between the outflow graft and bend relief could be observed, causing outflow graft obstruction. Patients on LVADs are still heart failure patients, in many cases with comorbidities. Therefore, many situations can occur requiring ICU treatment. Ethical aspects should always be the focus when taking care of these patients.

Introduction

Left ventricular assist device (LVAD) therapy is well-established in the treatment of patients with end-stage heart failure, although transplantation is still the gold standard. However, due to a shortage of donor organs, as well as the number of patients ineligible for transplantation, LVAD therapy has gained importance.[1,2] The early, pulsatile LVADs, such as Novacor® (WorldHeart, Ottawa) and HeartMate XVE® (Thoratec, Pleasanton, CA, USA), were bulky and showed a high adverse event (AE) rate. However, we could initiate our out-of-hospital program. The first patients on LVAD support could be discharged home.[3] The following generation of continuous-flow pumps showed some advantages in terms of ease of implantation, durability, and AE rates.[4] Although the percentage of biventricular assist device (BVAD) implantations was high (Thoratec® Paracorporeal Ventricular Assist Device [PVAD]; Pleasanton, CA, USA; Berlin Heart EXCOR®), the number of isolated LVAD implantations increased over time after a gain in experience. Constant developments and experience have led to the withdrawal of different pumps, and there are mainly two LVADs left on the market, namely the Jarvik 2000® (Jarvik Heart, Inc., New York, NY, USA) and the HeartMate 3® (HM3; Abbott, Abbott Park, IL, USA) (Figure 1).

Most recently, the distribution of the HeartWare™ ventricular assist device (HVAD) was ceased because of technical issues, as well as higher 1-year mortality and neurological event rates when compared to the HM3. Around 18,000 patients worldwide

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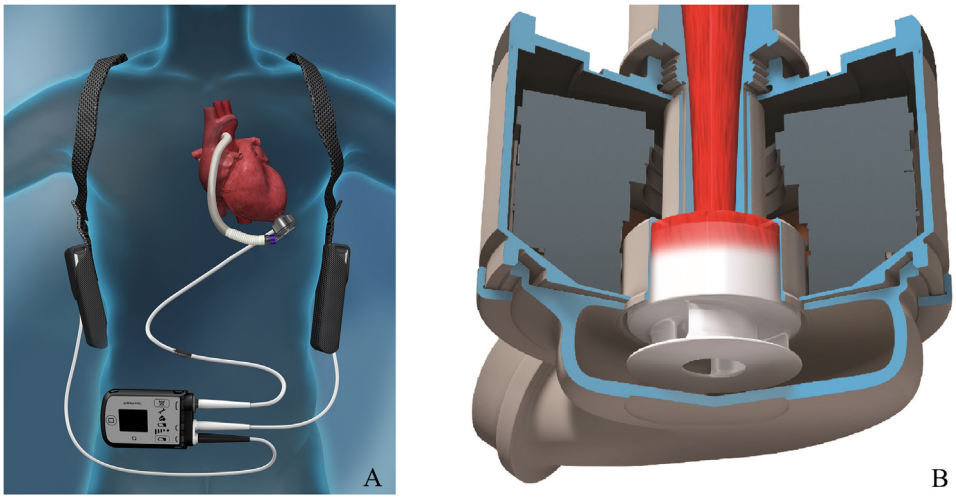

Figure 1. HeartMate 3 (HM3) system (A) and HM3 blood pathway with impeller (B).

were supported by the HVAD and 4000 are still ongoing and have to be taken care of.[5]

As a biventricular system, the Berlin Heart EXCOR® is available. Especially in the young population, this device is well-established due to the availability of several sizes of ventricles. It is the only mechanical circulatory support (MCS) system approved for pediatric patients and can be used as an LVAD, right ventricular assist device (RVAD), or BVAD.

As a total artificial heart (TAH), the Syncardia® was on the market but has not been available in Europe since 2022 due to certification issues. However, the number of patients on this device is very low. The CARMAT company (Velizy-Villacoublay, France) offers the biocompatible Aeson TAH®, which is certified but currently not available due to technical issues. As the number of ongoing TAH patients is very low, this paper will not focus on these.

Another option for biventricular support is the use of two centrifugal continuous-flow pumps, such as in the HM3. These devices are not approved for right ventricular support, but several reports have shown that it is feasible. Quality of life, despite two drivelines, two controllers, and four batteries, is acceptable.[6]

An LVAD can be implanted as bridge to transplant (BTT) or bridge to candidacy (BTC) in potential transplant candidates, or as bridge to recovery (BTR) and destination therapy (DT) in patients ineligible for heart transplantation. BTT candidates are on the device for long periods of time due to the shortage of donor organs. The number of patients on devices is increasing; however, the implant numbers are recently decreasing. The latter notion has to be discussed, as there is growing awareness of heart failure in general.

The HM3 is the only relevant LVAD remaining on the market, and studies showed lower incidences of AEs in comparison to its predecessors, the axial flow pump HeartMate II (HMII) and HVAD.[4] Despite these advances and developments, AEs still limit the prognosis in durable MCS and frequently require intensive care.

Infection

Infection plays a major role in the LVAD population. The Society of Thoracic Surgeons-Interagency Registry for Mechanical Assisted Circulatory Support (STS-INTERMACS) registry reported a patient rate of 41% experiencing a major infection within 12 months after LVAD implantation.[7] Infections have to be differentiated into VAD-specific infections (e.g., driveline or device infections), VAD-related infections (e.g., endocarditis), and non-VAD infections (e.g., pneumonia).[8]

Driveline infections (DLIs) are the most common ventricular assist device (VAD)-specific infections.[9] The driveline/skin interface is vulnerable to infections; thus, different tunneling techniques have been described. The driveline should be tunneled in or underneath the rectus muscle to create some barrier against ascending infections. A double-tunnel driveline technique can be helpful by first placing the driveline in the rectus sheath and then subcutaneously. Keeping the driveline-covering velour intracorporeal offers a silicon/skin interface, which may lead to a lesser incidence of ascending DLI.[2] An anchor patch dressing on the skin helps to stabilize the driveline. Furthermore, meticulous care should be taken with the driveline dressing changes, which are performed 1–3 times a week using an aseptic technique.[8,9] Patients and caregivers should be trained carefully. If signs of infection occur, immediate notification of the implanting center is mandatory. Early stage treatment may involve local and systemic antibiotic therapy and comprehensive wound management, and may avoid ascending infections.

Signs of systemic infection (fever, increased leukocytes, elevated C-reactive protein, elevated procalcitonin) are indications for readmission. Cultures from the exit site and blood specimens should be taken to identify the bacteria and tailor antibiotic therapy. Furthermore, imaging is necessary for the exact evaluation of the severity of the infection. Fluorine-18 deoxyglucose positron emission tomography (PET) is a helpful tool (Figure 2).[10]

Treatment varies from local treatment of the exit site to complicated surgical mediastinal revisions. Vacuum sponge therapy may be necessary.[11] Patients are hospital-bound for several weeks, and the vacuum sponges are exchanged twice a week. After eradication of the infection, the wound can be closed again. However, the reoccurrence of infection due to foreign material is frequent. If the pump housing or vascular outflow graft in the mediastinum is involved, reopening of the chest may be necessary to install vacuum therapy. Exchange of the LVAD device

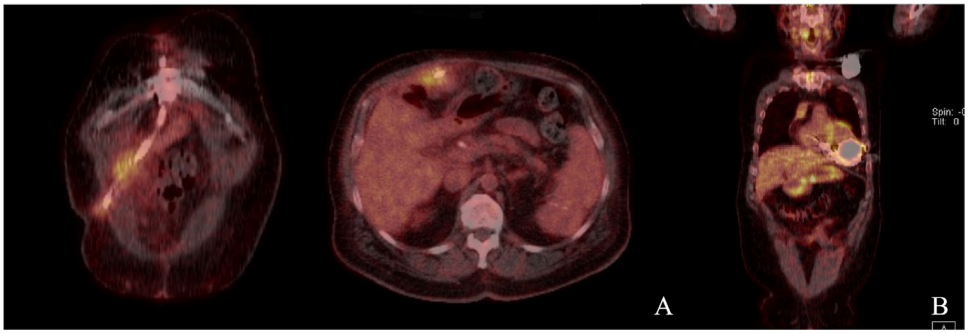

Figure 2. Positron emission tomography(PET) diagnostics shows isolated driveline infection (A) and device infection (B).

to eradicate the infection is an option, although perioperative risk and recurrence rates are high.[12] In patients eligible for transplant, urgent transplantation is the preferred option if the device is involved. If systemic signs of infection are controlled, transplantation is possible. Evacuation of the infected material (LVAD device, driveline, outflow graft) avoids recurrence.

VAD-specific infections are important causes of morbidity and mortality in the LVAD population. Systemic infections may lead to other complications, such as organ failure, exacerbation of anticoagulation with bleeding, or thrombotic issues. Driveline-free pumps are under development and could prevent some of the abovementioned complications. However, it remains to be determined whether and when such developments may be available.

Besides VAD-specific and VAD-related infections, the LVAD population is prone to other kinds of infections. Risk factors are older age, immobility, onset of organ failure, diabetes, and obesity. Rehabilitation programs and close follow-up can help avoid these issues.

Stroke/Neurological Events

In the latest report by the STS-INTERMACS registry, the rate of neurologic dysfunction in the LVAD population was 0.141 per patient-year, and up to 13% of patients experienced a stroke within 12 months after implantation.[7] The most reported neurologic events are ischemic stroke and intracranial hemorrhage. Risk factors for neurologic events are anticoagulation/antiplatelet therapy, acquired von Willebrand syndrome, elevated blood pressure (BP), infection, and non-adherence due to suboptimal anti-coagulation management.

The European Registry for Patients with Mechanical Circulatory Support (EUROMACS) demonstrated that the cumulative incidence rate of neurologic events was lower in patients supported with the HM3 device in comparison to HVAD.[13] Proper management of BP plays a major role. An elevated BP results in a high afterload of the LVAD, with subsequent low flow and potential stasis within the pump. Additionally, anticoagulation control is very important, and our patients conduct international normalized ratio (INR) self-management using CoaguChek™ (Roche Diagnostics). The consistency between traditional laboratory testing and CoaguChek™ is excellent.[14] Patients are advised to measure the INR on a daily basis to stay within the target range of 2.0–3.0 (aU).[2]

In case of neurologic symptoms, immediate admission is mandatory. Neurologic assessment and imaging (computed tomography [CT] angiography) should be performed to confirm the diagnosis and the cause (ischemic, hemorrhagic or hemorrhagic conversion, or vascular issues, such as aneurysm) and the extent of the neurologic injury. The anticoagulation levels should be checked and adapted. A multidisciplinary team should be involved, including neurology, neurosurgery, and the VAD center. In case of an embolic event, thrombolytic therapy or interventional thrombectomy may help to resolve the situation in selected cases.[15] Trepanation may be necessary in cases of increased intracranial pressure. Due to the patient's coagulation status, these procedures bear a high risk in this specific population.

In cases of intracerebral hemorrhage, temporary withdrawal of anticoagulation therapy and even normalization of coagulation may be necessary; preferably 4-factor prothrombin complex should be used.[16,17] Patients should be observed carefully for any change in symptoms, preferably in the intensive care unit (ICU). In BTT patients, eligibility for transplant must be reevaluated dependent on persisting symptoms. Urgent listing for heart transplantation can be a potential solution. Full heparinization after ischemic or hemorrhagic stroke (necessary to install extracorporeal circulation during heart transplantation) seems to be safe after 6 weeks. Repeated CT angiography is necessary to evaluate operability.

Beyond the eligibility for transplantation, suffering a disabling stroke leads to severe consequences for patients on LVAD therapy. Patients may require constant help, thus affecting their quality of life. In cases of severe stroke, palliation should be discussed. It is helpful if potential AEs are discussed before LVAD implantation, and this should be documented in a patient decree. Communication with the patient and relatives is extremely important in these situations.

Gastrointestinal Bleeding (GIB)

GIB is an important cause of readmission for LVAD patients. Several factors contribute significantly: shear stress in the device causing loss of von Willebrand factor multimers (acquired von Willebrand Syndrome) [18]; platelet dysfunction due to antiplatelet therapy; anticoagulation therapy by vitamin K antagonists; and development of arteriovenous malformations as a result of continuous flow.[19]

Careful evaluation of the causes of GIB is essential. An esophagogastroduodenoscopy and/or colonoscopy are mandatory. If a bleeding spot can be identified, treatment by coagulation or clipping is often possible. A push enteroscopy and/or video-

capsule endoscopy can be necessary if bleeding persists.[20] The incidence of GIB increases with age.[21]

Medical therapy is started with proton pump inhibitors, adaptation of anticoagulation, and blood transfusions. Reduction of anticoagulation by administration of 4-factor prothrombin complex concentrates may be necessary. Administration of vitamin K is contraindicated because of the unpredictable impact on INR levels. Especially in patients supported by the HVAD, the risk of pump thrombosis can increase significantly.

GIB tends to recur, and in those cases, withdrawal of antiplatelet therapy will be the first step in treatment, which may be followed by a permissive reduction of the INR target range to 1.5–2.0. Complete discontinuation of anticoagulation/antiplatelet therapy carries a high risk of thromboembolic complications or pump thrombosis and cannot be recommended. If the patient is a transplant candidate, a high urgent listing could be an option.

Right Ventricular Failure

The right ventricle (RV) offers preload for the LVAD, and its function determines exercise capacity and quality of life for the patients. In general, the function of the RV determines the success of LVAD therapy, and implantation of an LVAD has major consequences for the RV. Unloading of the left ventricle (LV) will decrease the filling pressure on the left side, which may decrease pulmonary artery pressure and decrease RV afterload. In terms of contractility, the RV is highly dependent on the LV, and the unloading of the LV under LVAD support causes changes in contractility. A septum shift toward the LV can cause RV contractile dysfunction. Precise adaptation of pump speed plays a major role in protecting the RV. However, despite all preventive measures, LVAD patients can develop RV dysfunction in the long term. Direct biventricular support by use of a BVAD or TAH may still not be favored, as sole LVAD therapy is superior in terms of mortality, morbidity, and quality of life. Although several risk scores for RV failure (RVF) are implemented, the predictability of RVF after LVAD implantation is still limited. In most cases, an LVAD will be implanted and may be escalated by the addition of a temporary RVAD. Indicators for such maneuvers may be an intraoperative central venous pressure (CVP) >15 mmHg, cardiac index (CI) <2 L/min/m^2, and the need for moderate or high inotropic support.[12] Thorough optimization of pump speed, reduction of pulmonary resistance by milrinone, sildenafil, iloprost inhalation, or nitric oxide may help to circumvent complications.

Systematic reviews showed a weaning rate from RVAD support of 23–100%.[22,23] However, the progression of the disease can cause late RVF in all patients. Late RVF is defined as hospitalization that occurs 30 days after LVAD implantation and requires intravenous diuretics or inotropic support for at least 72 h.[24] In the Mechanical Circulatory Support Academic Research Consortium (MCS-ARC) consensus document, [24] the diagnosis of RVF is made based on the following clinical findings: (1) the presence of two of the following: ascites, peripheral edema, or elevated jugular/CVP; (2) one of the following in association with clinical manifestations: renal failure, liver injury, reduction in pump flow (>30%), mixed venous saturation (SVO_2) <50%, CI <2.2 L/min/m^2, and lactate >3.0 mmol/L.

The prevention and medical management of late RVF is related to several factors, including intrinsic RV function (contractile state) and RV pre and afterload, as well as clinical factors, such as the presence of pulmonary, hepatic, and renal dysfunction.[25] Precise volume management is mandatory, and the use of loop diuretics or even hemofiltration may be necessary. Adaptation of pump speed can decrease RV afterload. Elevated pulmonary resistance can be treated by pulmonary vasodilators (sildenafil, nitric oxide, inhaled iloprost, and endothelin receptor antagonists). Guidance by right heart catheterization and echocardiography is necessary.[26] RV contractility can be improved by inotropes (dobutamine, milrinone, or intermittent levosimendan therapy). If the response of the RV is not sufficient or weaning is not possible, temporary or durable RV support may be necessary. In the case of heart transplant candidates, urgent listing is the preferred option.

Temporary RV support (Figure 3) [27] may be established without thoracotomy by placing a catheter over the jugular vein up into the pulmonary artery (outflow cannula) and a catheter into the right atrium over the femoral vein (inflow cannula). In cases of pulmonary impairment, an oxygenator can be implemented additionally. Alternatively, a dual-lumen catheter may be used (ProtekDuo®; Livanova PLC, London, UK). The Impella RP® Abiomed (Figure 3) [27] serves the same goal. The RV can be supported for a limited period; however, because of the catheter, the patient may be bedridden with impaired mobility. After stabilization, weaning off the RVAD should be attempted. If weaning is not possible, urgent listing is the preferred option for transplant candidates. If the patient is ineligible for transplantation, a durable RVAD may be placed [6] (Figure 4), although continuous flow centrifugal pumps are not approved for right ventricular support. The patient lives with two VADs, two drivelines, and with consequences regarding the quality of life. Implantation of two continuous flow pumps is feasible and carries acceptable results. Secondary implantation of a Berlin Heart EXCOR device is a less attractive option in these patients. If none of these options is suitable, palliation has to be considered.

Malignant Arrhythmias

LVAD therapy with LV unloading does not prevent malignant arrhythmias.[28] The clinical symptoms of ventricular tachycardia (VT) or ventricular fibrillation (VF) are different in individual LVAD patients; however, due to a reduction of RV function, the flow will decrease in all cases. Especially VF can lead to a low-flow situation, and these patients are at immediate risk of dying. However, in our clinical practice, we experienced patients on LVAD with VF remaining conscious despite VF. If pulmonary resistance is low, the CVP can be sufficient to overcome the pulmonary circulation and offers sufficient preload for the LVAD. Most LVAD patients wear an automatic implantable cardiac defibrillator (AICD). In cases of VT or VF, the patient may remain conscious, and the AICD discharge will be noted by the patient, which is traumatic. Adaptation of the AICD device is possible by increasing the discharge threshold and increasing the episodes of overstimulation. When patients enter the hospital, ECG monitoring will be the first step, and defibrillation after sedation will be performed if necessary. Recurrence will be avoided by medical antiarrhythmic therapy or possibly ventric-

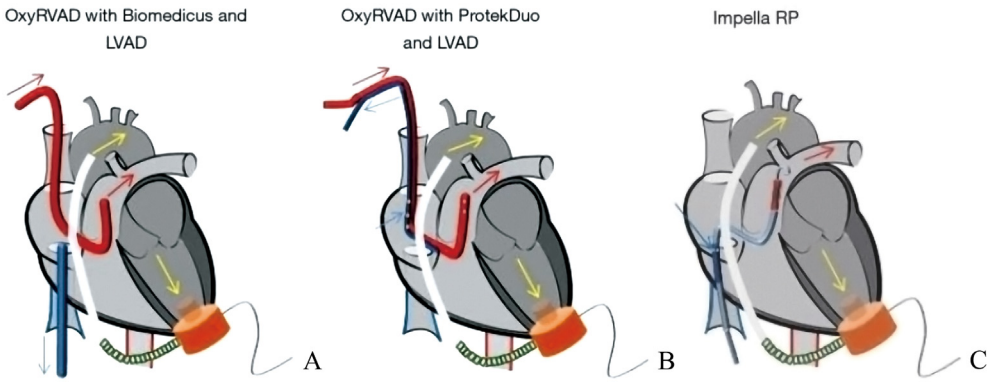

Figure 3. Catheter-based RV support with oxygenator, 2-catheter technique (A), ProtekDuo® technique (B) and temporary RV support by Impella RP® (C). LVAD: Left ventricular assist device; RV: Right ventricle; RVAD: Right ventricular assist device.

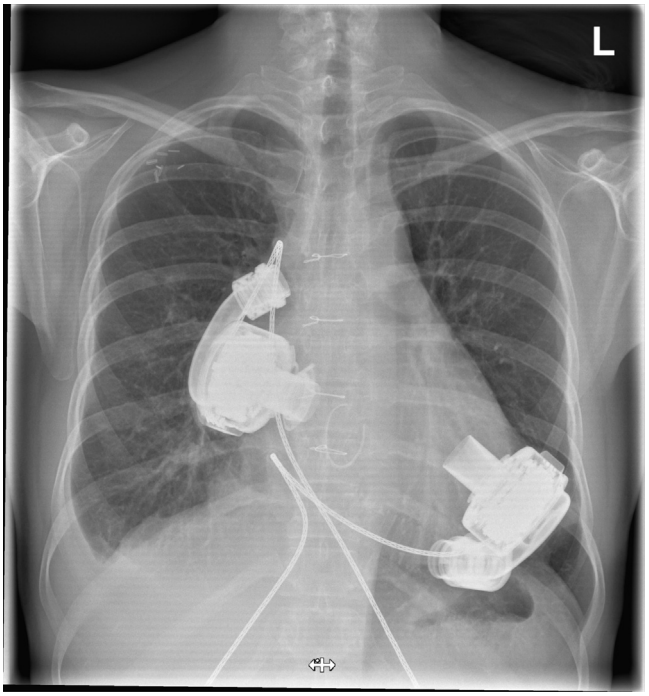

Figure 4. HeartMate 3 biventricular assist device.

ular ablation. If VT or VF episodes persist, heart transplantation or MCS for the right side may be considered.

Refractory malignant arrhythmias are a contraindication for LVAD therapy. Primarily transplant, a TAH or BVAD support should be prioritized.

Pump-specific AEs

HeartWare

A unique feature of the HVAD is its clinical waveform availability. Three immediately useful waveform characteristics to recognize are flow pulsatility (peak flow minus through flow), evidence of ventricular suction, and changes associated with systemic hypertension.

Flow pulsatility

Causes of low-flow pulsatility include the following: complete emptying of the LV, (too) high pump speed, RVF, tamponade, severe mitral or tricuspid regurgitation, acute arrhythmias, and significant aortic regurgitation (high mean pump flow with low flow pulsatility).

Ventricular suction

Suction waveforms are characterized by a rapid downstroke in the diastolic portion [29] caused by over-pumping with a small ventricular cavity and obstruction of the inflow cannula. A potential solution is a reduction of pump speed and improved hydration.

Systemic hypertension

Systemic hypertension is usually associated with an increase in flow pulsatility. Ventricular recovery can produce a similar waveform; thus, echocardiography is needed to distinguish the cause.[30]

Controller change

The manufacturer's recommendation is to exchange the HVAD controller every 2 years due to the internal battery within the controller. Controller failure is a critical alarm priority which needs immediate attention. If the failure leads to a pump stop, a controller change should be attempted to restart the pump. If possible, the patient should be brought into a clinical setting. If the controller exchange fails to restart the pump, inotropic therapy must be started, and possibly extracorporeal life support (ECLS) should be installed. Emergency LVAD exchange to HM3 is mandatory. Extra attention must be paid to the recently implanted HeartWare systems, since due to a manufacturing problem, restart issues after controller exchange are more probable. Controller exchange should only be performed in a clinical setting with adequate medical and surgical support.

Pump thrombosis

Pump thrombosis can occur in three different areas of the HeartWare system: inflow, intra-pump, or outflow graft.[31] A

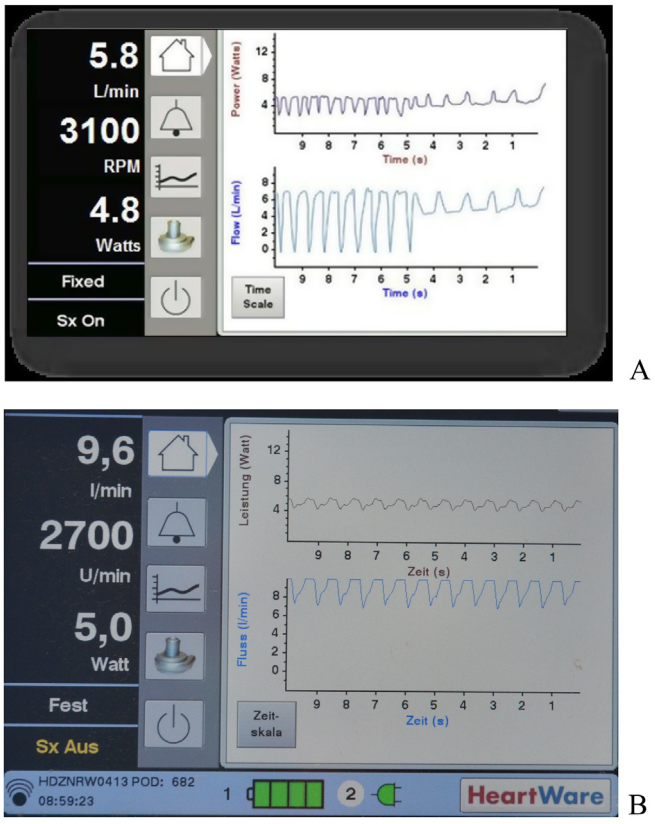

Figure 5. HeartWare™ ventricular assist device waveforms: A: in suction, B: pump thrombosis.

combination of the pump power waveform analysis, patients' clinical appearance, and blood samples (free hemoglobin, lactate dehydrogenase [LDH]) can identify the potential location and lead to the optimal therapeutic options [32] (Figure 5).

Inflow obstruction

Mostly this is caused by LV pannus and/or associated thrombus that occlude the inflow cannula. A sudden decrease in power uptake with a calculated low flow is the first sign. Typically, free hemoglobin or LDH will not rise because, despite obstructed inflow, erythrocytes will not be destroyed in most cases. Echocardiography will show an insufficiently unloaded ventricle. Direct visualization of the thrombus in the cannula is rarely possible; thus, we started to identify the thrombus by labeled platelets, but this research is at an early stage.[33] If the patient is stable and eligible for transplantation, urgent listing is a possibility. Otherwise, pump exchange to HM3 should be performed. Thrombolysis is not the preferred option in these cases, since due to the size and consistency of the obstructing thrombus, the chances of effective evacuation are low.

Intrapump thrombosis

In the case of intrapump thrombosis, the thrombus is caught in the impeller. This represents 70% of the cases of pump thrombosis.[32] Power uptake can increase suddenly or over weeks. Blood samples will show elevated LDH and free hemoglobin levels, and the urine can be hemolytic. Immediate therapy is indicated because a sudden pump stop can occur, and thrombolysis is the first-line treatment.[34] Careful preparation of the patient is necessary. Pre-thrombolysis cerebral and thoracic CT scans should be performed and the BP controlled to a mean of 70 mmHg. The thrombolysis treatment is administered in the ICU and stopped after the improvement of the waveforms. The reported risk of intracranial hemorrhage varies from 0% to 21%.[35,36] Pump thrombosis is a significant risk factor for future thrombosis. We apply thrombolysis twice, and if the pump thrombosis occurs a third time we exchange the pump for HM3.[37]

Outflow obstruction

Due to high flow, thrombosis within the outflow graft is rare and mostly seen in kinked grafts or narrowed outflow graft–aortic anastomosis. Furthermore, compression from outside by the driveline is a potential cause. The clinical appearance is similar to that of patients with inflow obstruction. The calculated flow will decrease slowly. A chest CT angiogram can visualize the obstruction, as can careful catheterization of the outflow graft. Surgical revision may be necessary. In most cases, the exchange of the obstructed part of the outflow can solve the problem.

HeartMate 3

As indicated before, the superior performance of the HM3 in comparison to the HVAD led to a stop in the global production and distribution of the HVAD. The AEs described in the subsection HeartWare are also present with the HM3; however, pump thrombosis is extremely rare [1] and issues with controller exchange have not been reported to date. Two potential events published in relationship with HM3 require attention.

Twisted outflow graft

After the introduction of the HM3, rare cases of outflow graft occlusion were observed, and twisting of the outflow graft was identified as the cause. The incidence was 1.6% in the Momentum 3 trial.[1] The manufacturer reacted quickly by introducing a clip which prevented twisting. Furthermore, 2 years ago, the assembly of the outflow graft was redesigned to avoid twisting issues. Twisting can be identified by a decrease in flow over days or weeks and CT can ensure the diagnosis. Several solutions are possible: (1) stenting of the outflow graft: because of potential debris in the outflow graft and mobilization of material by stenting, patients are at risk of embolic stroke; (2) de-twisting: by opening the assembling mechanism of the outflow graft, it is possible to de-twist the graft, and pump performance will return to normal immediately.

If debris in the outflow graft is diagnosed, the exchange of the outflow graft is the preferred option.

Obstruction of the outflow graft by bio debris

In rare cases, a gelatinous substance forms between the outflow graft and bend relief.[38] This can lead to obstruction of the outflow graft with similar symptoms as those described

in the subsection HeartWare. A CT scan will confirm the diagnosis. Potential treatment can be surgical or interventional; removing the bend relief will solve the problem.[39] Stenting is a valuable option. Acute and long-term results seem to be promising.

A special feature of the HM3 is the calculation of the pulsatility index (PI) which can be seen on the controller display. It reflects the differences in pump output in the systolic and diastolic phases of the cardiac cycle. These differences are generated by the contraction of the LV. A poor contracting unloaded ventricle will produce a low PI, a better contracting ventricle will lead to higher PIs. The PI can help set an adequate pump speed. Additionally, the PI can help identify potential problems; a sudden change can indicate a suction event. The patient should be trained to contact the hospital under these circumstances.

Discussion

LVAD therapy is well-established, and an acceptable quality of life can be achieved, especially in comparison to other patients with heart failure on optimal medical management.[40] Nevertheless, patients on LVAD therapy are still heart failure patients.[41] Mirza et al.[42] showed in a multicenter retrospective study including 450 LVAD patients that the mean peak oxygen uptake (PvO_2) was 14.1 ± 5 mL/kg/min (47 ± 14% of predicted value) at a median of 189 days (154–225 days) after LVAD implantation. They also showed that a lower PvO_2 was strongly associated with poorer survival in the LVAD population. Right heart catheterization showed borderline CI values in most cases, and heart failure medication normally had to be continued. Limited exercise capacity was also a consequence.

Infection is an important cause of morbidity and mortality in the LVAD population. As described in this paper, DLIs are still common, despite careful wound dressing. Ascending infections to the device or sepsis can have devastating consequences for the patients. Implantable controllers and batteries with transcutaneous energy transmission could help solve these issues. Fully implantable systems, on the other hand, present other challenges: (1) controller exchange is practically impossible (only surgical); (2) warming of the battery due to charging has to be limited to avoid tissue reaction; (3) to avoid battery exchange (surgical), many charge cycles should be allowed; and (4) the controller-patient interface should be established to transmit alarms.

As mentioned, the LVADs are implanted as BTT, BTC, BTR, or DT. Because of donor shortage, BTT patients are on the device for many years on average, as are DT patients who are ineligible for transplantation, which is contraindicated in most cases due to age. Therefore, the number of patients taken care of by our center has increased to 320 at the moment. To avoid serious AEs, close follow-up of the patients is mandatory:

The patient and relatives should be informed about potential AEs and the consequences for the quality of life before implantation of the LVAD. Setting up a patient decree can be helpful.

Training of the patient and relatives post-operatively should include the following: (1) wound dressing; (2) battery exchange–controller exchange; (3) alarms; (4) anticoagulation self-management (Coagucheck™); (5) home situation, placing home equipment; and (6) emergency cases, how to behave.

The VAD coordinators are on call 24/7, and patients are instructed to call in case of any questions or emergencies. The well-trained coordinators can instruct patients and take further steps if necessary. In-hospital capacity has to be reserved for emergency cases.

Patients visit the outpatient clinic following an algorithm: (1) 4 weeks after discharge; (2) then every 3 months; (3) after 2 years, twice a year; secure surveillance can avoid serious AEs and prevent further deterioration.

Conclusions

Dependent on the size of the LVAD program and the number of patients on the device, a certain number of patients will enter the ICU with VAD or VAD-related issues. AE rates have decreased over the years, but we are still dealing with a patient population that has heart failure with VAD- or HF-associated comorbidities. These patients may be frail and of advanced age, especially DT patients. These patients can be challenging and should be treated by a multidisciplinary team. Communication with the patients and relatives is key. Ethical aspects should be considered in all circumstances.

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Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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