



Long-term ventricular assist devices in current clinical practice

Dugotrajne ventrikularne pumpe u savremenoj praksi

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Introduction

Chronic heart failure (CHF) is a major healthcare issue associated with significant reduction of the quality of life, poor prognosis – high mortality rate, and still no adequate therapeutic approach available to the majority of the patients.

Statistics indicate that survival rate for patients with CHF is only 50% after 5 years, and significantly less so for those with advanced heart disease, less than 50% after one year. Incidence and prevalence of CHF are also on the increase with more than 16 million diagnosed across Europe and United States – 2.5% of total population, resulting in frequent hospital admissions and long term costs of palliative support. Further still, numbers indicate significant increase of CHF in elderly patient group (65+ years of age), population here expected to double over the next 20 years¹⁻³.

Although, numerous advancements in medical therapy have improved patient outcomes in CHF, prognosis is still poor and the quality of life remains limited. For patients with end-stage heart failure, heart transplant (HTX) remains to be the only long-term satisfactory option. However, the increasing demand of donor organs is not equilibrated with limited number of available hearts. Current estimates indicate that up to 100,000 patients meet criteria for HTX in the United States⁴. The scarcity of donor organs has fuelled the development of interim interventions such as different types of cardiac surgery operations aimed at restoration of left ventricle geometry and functionality, cardiac resynchronization therapy (CRT) and mechanical circulatory support (MCS). According to the Registry of the International Society for Heart and Lung Transplantation – the 25th Official Adult Heart Transplant Report – 2008, almost 29% of patients at the time of transplant were on some type of MCS

modality (22% on left ventricular assist device-LVAD)⁵. Technology advancements resulting in smaller MCS units offer alternative and permanent treatment option for many patients on the heart-transplant waiting list thus mitigating mortality rate².

A ventricular assist device (VAD) is a mechanical pump that provides circulatory support in patients with either acute or chronic cardiac failure – when heart can no longer pump blood effectively^{6,7}. Initially, VADs offered temporary mechanical circulatory support for those patients not expected to survive until a new organ became available. Reports of long-term success using VADs indicated possibility of permanent cardiac assist⁸. Today, VADs are frequently applied to varied purpose goals including use as a bridge to transplantation (BTT), destination therapy (DT), a bridge to recovery (BTR) – aiding natural heart in the recovery process by relieving some of the pressure, and a bridge to a decision (BTD) – an evolving paradigm in management of patients who present in acute cardiogenic shock. VADs are most commonly used to support the left ventricle (LVAD), but right ventricular (RVAD) devices are also used, including biventricular support (BiVAD). The basic idea behind any kind of MCS is to provide adequate end-organ perfusion in order to avoid irreversible multi-organ system failure and, if possible, to reduce the work-load of the failing ventricle thereby allowing function recovery (although only a small portion of patients with an idiopathic cardiomyopathy have the potential to myocardial recovery). The pumps are designed to pull blood from the failing ventricle (to unload the chamber) and expel it to the corresponding large vessel and further into circulation. The pump has an inflow cannula that channels blood from the ventricle or atrium to the pump, and an outflow cannula that channels blood from the pump to the

aorta or pulmonary artery. Depending on the site of the pump, VADs can be classified as intracorporeal (inside the patient), extracorporeal (outside the body) or paracorporeal (immediately adjacent to the patient).

A pivotal randomized study that investigated the effect of mechanical assist devices as a DT on the outcome and quality of life in patients with CHF was the Randomized Evaluation of Mechanical Assistance for the Treatment of Congestive Heart Failure (REMATCH) trial³. In this landmark trial, a total of 129 patients with end-stage heart failure – New York Heart Association (NYHA) class IV – who were ineligible for cardiac transplantation were assigned to receive a LVAD (68 patients) or optimal medical management (61 patients). “The rates of survival at 1 year were 52% in the device group and 25% in the medical-therapy group ($p = 0.002$), and the rates at 2 years were 23% and 8% ($p = 0.09$), respectively”³. The final conclusion of the trial was that the use of a LVAD in patients with advanced heart failure resulted in a prolonged survival period and an improved quality of life and as such, LVADs may be considered as an acceptable alternative therapy in selected patients who are not candidates for HTX. This trial was the first to establish the efficacy of device therapy for end-stage heart failure and set the standards for CHF treatment using VADs.

Depending on the level of ventricular reserve or residual volume in the left ventricle to open the aortic valve and generate a pulse, LVAD may be added to support the circulation in two ways. With total unloading of the left ventricle, LVAD is connected to the systemic circulation in a serial manner and the aortic valve is closed all the time⁸. If the failing myocardium has the capability of generating a pulse, the pump is added to the circulation in a parallel fashion – both the device and the native ventricle can pump blood into the ascending aorta. Aortic valve may open, usually during exercise when veins contract and produce increased venous return to the heart.

As a result of significant technological advancements with mechanical pumps in the last decade and their profound impact on the mainstream of our daily practice, guidelines for the CHF treatment need to be regularly updated. Guidelines are expected to be published by all major bodies, including International Society for Heart and Lung Transplantation, American Heart Association and American College of Cardiology Task Force, and the Heart Failure Society of America⁹. One may expect that these guidelines will recommend that every patient with refractory end-stage heart failure should be considered and evaluated for some kind of MCS. The Centre for Medicare and Medicaid Services requires that patients exhibit NYHA class IV symptoms (optimal medical therapy refractory patients) to qualify for MCS therapy¹⁰. Currently, MCS is recommended to those patients facing imminent death due to heart failure still having sustained end-organ function. In other words, candidates for long-term assist devices are those with inadequate hemodynamics despite optimized drug therapy and/or intra-aortic balloon pump assistance¹¹. Hemodynamic parameters that may guide selection of patients suitable for device therapy include: pulmonary capillary wedge pressure (PCWP) of >20

mmHg, a cardiac index of $\leq 2 \text{ Lmin}^{-1}\text{m}^{-2}$, and a systolic blood pressure $\leq 80 \text{ mmHg}$. However, interpretation of hemodynamic profiles may be very difficult in certain cases emphasizing the need for thorough clinical assessment and careful decision making.

A study from Holman et al.¹² included a total of 420 patients with 497 implanted assist devices (314 LVADs, 5 RVADs, and 77 BiVADs). The authors found that older age, ascites, increased bilirubin, and Interagency Registry for Mechanically Assisted Circulatory Support (INTERMACS) level 1 (cardiogenic shock) may be regarded as independent risk factors for mortality. A similar study using multivariate analysis on data from 47 patients receiving LVAD found that the preoperative total bilirubin value, age, and preoperative right heart dysfunction are independent predictors of unfavourable outcome and death¹⁰. These findings underscore the importance of proper patient selection and early implantation of LVAD¹³.

This paper briefly reviews currently available VAD systems for long-term support of the left ventricle (with the focus on HeartMate II and HeartWare), their role in today's clinical practice, patient selection, observed complications, and further directions in this rapidly advancing field.

Historical notes

The history of MCS goes back into the beginning of modern cardiac surgery and provides some insight into the development of indications and corresponding clinical impact. It followed the growth of cardiac surgery procedures which established a need for developing means of extending circulatory support for patients who could not be weaned from CPB following cardiac surgery¹⁴. The primary focus in this field was to develop a total artificial heart (TAH), but this has had limited success and, as a result, shifted attention to VADs². The first devices were invented (Dr. Hall and Dr. Liotta) and used (Dr. Crawford) in the setting of short-term support in a patient with post-cardiotomy heart failure in 1963¹⁵. The patient underwent aortic valve replacement developing acute heart failure which was treated by VAD implantation that enabled him to live for 4 more days. A similar device was successfully implanted by Dr. DeBakey in 1966 in a 37 year old woman who was supported for 10 days and became the first long-term survivor after using this technology¹⁶. In 1969, Dr. Cooley was the first to use an artificial heart to bridge an acutely deteriorating patient to transplantation 3 days later¹⁷. The first implantation of an artificial heart as a permanent heart replacement was performed by Dr. DeVries in 1982. The first Clinical VAD program has been announced in the period 1975–1978 by National Heart, Lung and Blood Institute (NHLBI) through request for proposal (RFP) – devices had to be able to provide circulatory support for at least 2 years with no “break of the skin”. In 1994 another RFP, this time for “Innovative Ventricular Assist Systems” was announced by the same organization. The contractors, such as: Thermo Cardiosystems, Baxter, Abiomed and Thoratec Labs, were subsequently engaged into the development process⁸. By 1986, a total of 41 patients had undergone VAD implantation, and more than

20,000 device implantations occurred worldwide since then (around 55% being HeartMate II).

An ideal VAD

An ideal VAD would be durable, capable of providing long-term reliable systemic flows, sufficient to meet metabolic needs over a substantial range of physical activity (self-adjusting operational mode), small in size, easy to implant (preferably intrapericardially)¹⁸. The device should produce minimal immunobiological response; it would have to be resistant to infection, with minimal risk for complications (thrombosis, bleeding, and haemolysis), possibly not requiring permanent anticoagulation therapy, consuming small amount of electrical power thus not requiring an external power source. The device should also be affordable and readily available, providing short learning curve for physicians as for the patients.

Currently, there are three generations of VADs available for clinical application (Table 1). The classification of

number of patients has been successfully supported with these devices which remain in use today for selected patients.



Fig. 1– Thoratec HeartMate XVE (with permission from Thoratec Corporation).

Table 1

Major characteristics of different pump generations

Characteristics	First generation pumps	Second generation pumps	Third generation pumps
Operational method	Pulsatile chamber with volume displacement by external compression	Spinning rotor mounted on a central shaft	Hydrodynamic and/or electromagnetic suspended spinning rotor
Type of flow	Pulsatile	Constant, nonpulsatile	Constant, nonpulsatile
Devices	HeartMate XVE, Novacor, Thoratec PVAD and IVAD, Abiomed 5000	HeartMate II, Jarvik 2000, MicroMed DeBakey	HVAD, VentrAssist, Terumo Dura Heart, HeartQuest

the devices into three distinct generations does not only imply the order in which they appeared, but also functional properties, generated flow characteristics and mechanical design among other things.

First generation VADs

Initially, the first devices that were developed relied on the close imitation of the basic circulatory physiology and its inherent property – pulsatile flow. These devices (first generation VADs) were developed during 1970s and 1980s and were characterized by the use of positive volume displacement and pulsatile flow. The first generation generally consists of pumps such as the Thoratec PVAD/IVAD, the HeartMate IP/VE/XVE (Figure 1), and the Novacor LVAS. Although provided satisfactory circulatory support allowing improved survival until HTX, the first generation pumps had many limitations, such as big size that required substantial surgical dissection for the placement of the device, noisy pump operation, presence of a large diameter driveline and, most importantly, limited mechanical durability due to its mechanical construction². The first generation pumps were also related to serious complications including bleeding, infections and thromboembolic events. It was the HeartMate XVE that was used in the REMATCH trial³ to compare medical and circulatory assist device treatments for end-stage heart failure. Despite the obvious problems, a great

Second generation VADs

Growing waiting lists for HTX and long waiting times of up to 1 year have been urging the need for more reliable and smaller devices¹⁹. Although the first generation pumps completely relied on the imitation of the physiologic property of the circulation – its pulsatile nature – introduction of the continuous flow pumps into everyday clinical practice was milestone concept that fundamentally changed the notion of human circulation physiology. Pulse is not strictly necessary despite evolutionary adaptation of the human body to pulsatile circulation. That said, continuous flow VADs are able to mimic physiologic flow only to a certain extent – a special mode of operation (pulsatility index) that permits aortic valve opening during the systole. Pulsatility index is defined as the magnitude of flow pulse provoked by the pump through each cycle²⁰. Continuous flow pumps use electrical energy to rotate an axle on which a turbine or propeller system is mounted to pushing the blood through the body at a steady rate. These devices have now largely replaced use of the first generation pulsatile, volume displacement pumps. Second generation pumps have no requirements for external venting – one of the reasons for their reduced size¹⁸. Second generation rotary pumps are characterized by an axial blood flow path suspended by contact bearings and an internal rotor driven by an electromagnetic field². The basic principle employed has been known for years – Ar-

chimedus' screw. Rotation of the rotor provides the driving force to propel the blood from the left ventricle through the pump and into the circulation. However, the system works on high rotational speeds²¹, heat is generated, haemolysis with damage to the blood cells and thrombi may occur²². Anaemia and platelet damage along with the activation of contact coagulation system may also ensue⁸. Main advantages of these pumps are smaller size enabling easier implantation (even in small bodies), improved durability due to its design characteristics (only one moving part), less electricity consumption, improved survival and quality of life, reduction of post-implantation adverse effect (bleeding, thrombosis, infection). The control systems and power delivery mechanisms are easily portable and manageable by the patient.

Second-generation rotary pump LVADs were first introduced with the development of Hemopump. Researchers have applied its design to other circulatory assist devices (particularly HeartMate II). Subsequently, the Jarvik 2000 in 1999 and HeartMate II LVADs in 2000 have been used to support patients to HTX¹⁴. Up to date, the HeartMate II is the most successful second-generation pump worldwide and Food and Drug Association (FDA) approved as BTT and DT²³⁻²⁵. Eligibility criteria are essentially the same as those used to select patients for the pivotal clinical trial that included patients with shortness of breath and/or fatigue at rest or during minimal exertion despite treatment with optimal therapy for heart failure associated with a low ejection fraction (<25%) who were not candidates for HTX due to their age or comorbid conditions²⁶.

The physiologic response to the reduced arterial pulse or its absence during support with continuous flow pumps is not completely understood and it is unclear whether any adverse effects may surface in patients to be supported for many years²⁷. Clinical experience to-date indicates that no detrimental effect of these devices on end-organ function is to be expected in the long term^{28,29}. There is a major shift among most VAD programs towards implantation of continuous flow devices though discussion about the flow modalities remains relevant³⁰.

HeartMate II

The HeartMate II (Thoratec Corp.) LVAD is an axial flow pump that had its origin in the early 1990s (Figure 2) and is intended for long-term support for BTT and DT in patients with CHF^{31, 32}. The HeartMate II contains a rotor (spinning impeller – the only moving part) capable of producing flow rates greater than 10 L/min at resolutions ranging from 6,000 to 15,000 rpm (Figure 3). HeartMate II is approximately one seventh the size and one fourth the weight of the XVE pump. The pump can be implanted in a pre-peritoneal fashion or intra-abdominally, with the inflow cannula connected to the left ventricle (the apex of the heart), and the outflow graft sutured to the ascending aorta. A driveline connected to the pump should be routed transcutaneously, usually in the region of right upper quadrant of the abdomen. Power is delivered by external power sources – rechargeable batteries – that enable ambulence of the patient.

The system is operated at a fixed rotational speed set by the clinician with the aim of providing optimal circulatory support for each patient. Although the internal surfaces of the device were designed to help resist the development of thrombi, anticoagulation is at present recommended to keep INR between 1.5 and 2.5.



Fig. 2 – Thoratec HeartMate II device (with permission from Thoratec Corporation).

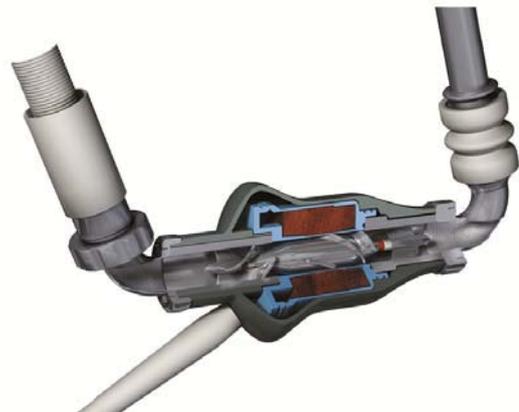


Fig. 3 – Thoratec HeartMate II device – construction design (with permission from Thoratec Corporation).

The blood pump component of the device is a titanium straight tube of 12 mm in diameter and contains the inlet stator, a pump rotor and the outlet stator (Figure 3). The rotor (the only moving part of the device) contains a magnet that fits in close proximity of the motor. A magnetic field is generated between the rotor and the motor producing torque and rotary motion that creates blood flow³³. The blood flow is directed from the ventricle through the inlet cannula to the pump and then through the outlet cannula via an outflow graft to the aorta. The inner surfaces of the inflow conduit and the outflow graft contain a textured surface to simulate natural endothelial surface for blood flow.

Of all the continuous flow pumps currently in the use worldwide, only the Thoratec HeartMate II VAD has received approval from the US Food and Drug Administration (FDA) for use as BTT and DT in the United States³⁴.

The BTT pivotal multicentre, nonrandomised trial initially enrolled 133 NYHA class IV patients who were listed for cardiac transplant and were at imminent risk of dying³⁵. The primary outcome of the BTT trial was survival to HTX or cardiac recovery, or being listed as United Network for Organ Sharing (UNOS) status 1A or 1B at 180 days of LVAD support. Of the 133 patients enrolled, 100 patients (75%) reached the primary end-point of HTX, cardiac recovery or survival at 180 days with ongoing mechanical support. The group of 100 patients included 56 patients who underwent HTX, 43 patients continued to receive LVAD support and were eligible for HTX, and 1 patient whose cardiac function recovered leading to LVAD explant. The overall rate of survival to HTX, recovery, or continued support was 75% at 180 days. The overall actuarial survival for patients continuing to receive HeartMate II device support was 89% at 1 month, 75% at 6 months and 68% at 12 months (the median LVAD support was 126 days).

After being FDA approved in 2008, a multi-institutional study was carried out using the INTERMACS database comprised of 169 consecutive BTT patients³⁶. The study compared the effectiveness of HeartMate II and previously approved LVAD devices such as the HeartMate XVE and Thoratec IVAD. The 6 and 12-month survival of HeartMate II patients was 90% and 85% respectively whereas the control group using pulsatile devices had 6 and 12-month survival of 79% and 70% respectively. Significant reduction of device related complications was also observed for HeartMate II group (infection, neurological dysfunction, renal and respiratory dysfunction).

Another trial was carried out to evaluate effectiveness of HeartMate II device as DT in patients ineligible for HTX²⁵. The study was conducted in 38 centres in the USA. Patients were randomly assigned to undergo implantation of the HeartMate II continuous flow device or HeartMate XVE pulsatile device in a 2 : 1 ratio (a total of 200 patients – 134 in the continuous flow device arm and 66 in the pulsatile device arm). The trial compared these devices with established composite end-point of survival free from disabling stroke or reoperation to repair or replace the device for mechanical failure over a 2-year period (46% and 11% for HeartMate II and HeartMate XVE respectively). Overall 2-year survival was 58% and 24%, respectively; again with significant reduction of adverse events in HeartMate II group. In total, 21 pump replacements (and 3 device explantations) were required in the pulsatile LVAD cohort as opposed to only 13 pump replacements in the continuous flow device group ($p < 0.001$). After enrolment of the initial 200 patients in the DT trial, hundreds of additional patients have been enlisted part of continued access protocol³⁴.

Despite a dramatic improvement in survival with the HeartMate II, there still remains the burden of morbidity associated with the device, including infection, bleeding, and thromboembolic events³⁶. According to the INTERMACS

annual report, the event rates (events per 100 patient months) during the first 12 months of HeartMate II therapy in BTT patients were 17.41 for bleeding, 11.8 for infection, and 1.93 for neurologic dysfunction²³.

Third generation VADs

During their extensive clinical use, it became apparent that implantation of second generation pumps in a form of BiVAD is extremely challenging if not impossible in cases of miniscule patients. An idea of developing even smaller devices that can be implanted within pericardial cavity emerged as an option to tackle the problem of BiVAD implantation and unsuitable patient's anatomy.

Further advancement in design and construction of the continuous flow pumps has led to development of bearingless devices, which in theory ought to be more durable than the previous generation pumps, and due to their smaller size allow intra-pericardial placement. Third generation VADs are continuous flow pumps broadly classified based on pump design into centrifugal and axial flow devices, and on whether the impeller is hydrodynamically or magnetically levitated. Levitation systems of third-generation rotary blood pumps suspend the moving impeller in pump thereby removing mechanical contact². Centrifugal flow pumps have cone-shaped or cylindrical rotors that drive the blood flow using the centrifugal force generated from the centre of the rotor to its circumference³⁷. One anticipated benefit is that the centrifugal design results in a flatter and more sensitive pressure flow curve at lower rounds-per-minute (RPM) compared to axial flow devices¹⁷. Examples from this heterogeneous group are the DuraHeart (Terumo Heart, Inc., Michigan), VentrAssist (Ventricor, Australia), CorAide (Arrow International, Pennsylvania), HeartWare HVAD (HeartWare, Inc., Massachusetts) and Levacor (World Heart, Inc., Oakland, CA) systems.

HVAD

The HVAD (HeartWare Inc.) is a small third-generation continuous flow rotary pump with a centrifugal and bearingless design (Figure 4). What distinguishes this pump from other of its generation is the size – the pump is small enough to be placed inside the pericardial cavity (no need for pump



Fig. 4 – HVAD (with permission from Heartware Inc.).

pocket) at the apex of the heart or left ventricle inferior wall. As a consequence, surgical trauma to the surrounding tissue is significantly reduced while the implantation procedure is simplified – not requiring abdominal incision for implantation. It usually operates at a speed of 2,400–3,500 RPMs and can provide up to 10L/min of flow¹³. The impeller is suspended in place by a combination of passive magnetic and hydrodynamic bearing systems, avoiding mechanical contact and wear (Figure 5)¹⁸. Physical contact between the casing and the impeller is prevented by a thin blood film generated by the hydrodynamic bearings^{38–40}. The device was implanted for the first time in humans in 2006 and, since then, it has been clinically evaluated in Europe (approved for BTT) and Australia with an ongoing bridge-to-transplantation trial in the US.



Fig. 5 – HVAD – internal design (with permission from Heartware Inc.).

The HVAD is implanted through a median sternotomy with the assistance of cardiopulmonary bypass. An integrated inflow cannula is inserted into the left ventricle through the apex and is held in position by an adjustable sewing ring while pump is positioned in the pericardial cavity. Afterwards, the 10 mm outflow graft is anastomosed to the ascending aorta (Figure 6)⁴¹.

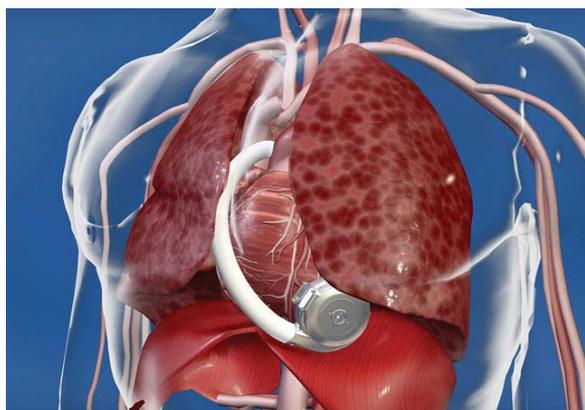


Fig. 6 – HVAD position inside the chest (with permission from Heartware Inc.).

The HeartWare device has been evaluated in several clinical trials in terms of patient survival and quality of life. A recent multicentre trial in Europe and Australia found that

the actuarial survival after 6 and 12 months following HVAD implantation was 91% and 86%, respectively⁴². Another multicentre, non-randomized trial that included NYHA IV class patients, evaluated the safety of HVAD⁴³. Fifty patients were included in the trial and they were supported using HVAD for 180 days until HTX, myocardial recovery, device explantation or death with following actual survival at 6, 12, and 24 months: 90%, 84%, and 79% respectively. Death as an end-point was reached in 9 cases (18%) – 3 patients died as a result of sepsis, 3 from multi-organ failure, and 3 from haemorrhagic stroke. The most frequent adverse events were infection and bleeding.

The ongoing Evaluate the HeartWare Ventricular Assist System (ENDURANCE) trial may demonstrate an important clinical advantage of this device.

Complications

Since growing number of patients are being supported with VADs for extended period of time, the interaction between the body and the VAD during long-term or even life-long period and the management of complications have gained the interest of clinicians and biomedical engineers⁴⁴.

Thrombosis, thromboembolic events and the risk of bleeding

After the implantation of the device blood is exposed to a foreign surface requiring the use of systemic anticoagulation. Manufacturer guidelines for continuous flow devices recommend use of both antiplatelet and anticoagulation therapy in order to reduce the risk of pump thrombosis and consequent thromboembolism³⁷. Although the first recommended range of the international normalized ratio (INR) for the patients with HeartMate II was 2.5 to 3.5, the target INR has been recently decreased due to greater risk of bleeding^{35,45}.

It has been noted that some patients may develop thrombosis of the aortic root and the ascending aorta – especially when the outflow graft is implanted into the descending aorta⁴⁴. In these settings, HTX should be performed on an emergency basis, if possible. In the case of pump thrombosis, immediate pump exchange is mandatory. All other thromboembolic events should be dealt with in the usual manner.

The incidence of any-cause bleeding (requiring red blood cells transfusion or necessitating surgery) with different types of VAD ranges between 0.16 and 2.45 events per patient per year while the incidence of thromboembolic events is 0.05 to 0.28 events per patient per year^{42,46}. Overdosing of anticoagulant therapy has been the major factor for elevating the risk of bleeding in patients on VADs. However, there has been growing number of reports of an increased incidence of gastrointestinal mucosal arteriovenous malformations (AVM) – pre-existing or newly developed due to loss of physiological pulsatility, and acquired von Willenbrand disease associated with axial flow devices³⁷. It remains unclear whether gastrointestinal bleeding is related to the need for anticoagulation or whether it is linked to continuous flow effect (loss of pulsatility)⁴⁷. In some patients, severe

haemolysis may occur after VAD implantation. This is usually seen when the rotor speed in the continuous flow pumps is set to higher operation mode or as a result of postoperative complications (malposition of the apical cannula, pump thrombosis, outflow graft kinking)^{44, 48, 49}.

Infections

Infectious complications associated with VAD placement are often encountered, although the rate has improved with the new generation devices⁵⁰. Infection can involve any portion of a VAD – surgical site, driveline, pocket or the pump itself. Most infections involve the percutaneous driveline^{51, 52}. Length of device support was associated with more than 50% of 1-year survivors developing a driveline-related infection⁵³. The rate of driveline infections appears to have reduced after the introduction of newer generation pumps most likely due to smaller drivelines used by these pumps as well as the reduction in movement of the device within a surgically fashioned pocket²⁵. Another potential site of infection is the pump pocket usually originating from the driveline infection or secondary to surgical trauma or hematoma formation⁵⁴. The infections is most likely to be caused by *Staphylococcus aureus*, *Corynebacterium* or *Pseudomonas aeruginosa*⁴⁴.

Aortic valve pathology

Patients treated with long-term continuous flow devices are at higher risk of developing aortic insufficiency (AI) or some degree of aortic valve degeneration³⁷. It is believed that this may be the result of reduced (limited) or absent opening of the aortic valve mostly seen when the device is working in the serial fashion with continuous load of the left ventricle. The fusion of the aortic leaflets may be seen as early as 6 months following implantation. This complication

is encountered in approximately 25% patients, and several risk factors have been designated: aortic root diameter, female sex, non-pulsatile flow⁵⁵. After 18 months on device support, up to 50% of patients present with moderate or severe AI⁵⁶.

Mechanical complications

Although rare, complications such as device malfunction, inflow conduit rupture, and driveline break may occur. It is important to establish the correct cause of malfunction which, in most cases, requires device exchange. Despite modern technology and the use of high resistant materials, cable damage⁵⁷, due to kinking and twisting, or as a result of a suicide attempt occurs with an incidence of 5%–9% or up to 0.06 events per patient per year^{27, 44, 58, 59}.

Conclusion

Currently, long-term circulatory support with VADs offers viable choice for end-stage heart failure patients, either as BTT option or as DT. Survival rate along with the quality of life of these patients have been significantly improved. Patients supported with VADs continue to be affected by a variety of complications – the fact that only emphasizes the need to further improve this technology. Meticulous risk-benefit evaluation by a multidisciplinary team is mandatory for each patient in order to achieve optimal survival and minimize the risk of morbidity.

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