

Joint British societies and transplant centres guideline on management of emergencies in implantable left ventricular assist device recipients in transplant centres

- ¹ Harefield Hospital, London
- ² Faculty of Intensive Care Medicine, London
- ³ Intensive Care Society, London
- ⁴ Golden Jubilee National Hospital, Glasgow
- ⁵ Royal Papworth Hospital, Cambridge
- ⁶ University Hospitals Birmingham, Birmingham
- ⁷ Resuscitation Council UK, London
- ⁸ Society for Cardiothoracic Surgery in Great Britain & Ireland, London
- ⁹ Wythenshawe Hospital, Manchester
- ¹⁰ Freeman Hospital, Newcastle
- ¹¹ British Association of Critical Care Nurses, Newcastle
- ¹² British Cardiovascular Society, London
- ¹³ Association of Cardiothoracic Anaesthesia and Critical Care, London

Word count: 3058

Abbreviations

LVAD left ventricular assist device, CPR cardiopulmonary resuscitation, ALS Advanced Life Support, ECMO extracorporeal membrane oxygenation, MAP mean arterial blood pressure, VT ventricular tachycardia, VF ventricular fibrillation

Abstract

An implantable left ventricular assist device (LVAD) is indicated as a bridge to transplantation or recovery in the United Kingdom. As a result of a persistent shortage of donor hearts, LVADs perform a vital role in the management of patients with advanced heart failure, allowing them to live semi-independently in the community.

The mechanism of action of the LVAD results in a unique state of haemodynamic stability with diminished arterial pulsatility. The clinical assessment of an LVAD recipient can be challenging because non-invasive blood pressure, pulse and oxygen saturation measurements may be hard to obtain. As a result of this unusual situation and complex interplay between the device and the native circulation, resuscitation of LVAD recipients requires bespoke guidelines.

Through collaboration with key UK stakeholders, we assessed the current evidence base and developed guidelines for the recognition of clinical deterioration, inadequate circulation and time-critical interventions. Such guidelines, intended for use in the in-hospital setting, are designed to be deployed by those providing immediate care of LVAD patients under conditions of precipitous clinical deterioration.

In summary, the Joint British Societies and Transplant Centres LVAD Working Group present the UK guideline on management of emergencies in implantable LVAD recipients for use in advanced heart failure centres.

Introduction

A ventricular assist device (VAD) is a mechanical blood pump which replaces or supplements native ventricular hydraulic function. VADs can be used to support the left, right or both side of the circulation and are designed for either short or long-term use. This article pertains specifically to recipients of implantable (long-term) left ventricular assist devices (LVAD).

LVADs are deployed as treatment for advanced heart failure in patients who are refractory to medical therapy. In the UK, implantable VADs are commissioned at six adult cardiothoracic centres as a bridge to transplantation or native heart recovery¹. They are typically implanted when no suitable donor heart can be found due to time constraints, elevated human leukocyte antibody levels and donor size matching. They can also be used when there is a contraindication to heart transplantation such as pulmonary hypertension that is deemed to be reversible using LVAD therapy.

The current generation of LVADs are centrifugal blood pumps comprising a rotating impeller which is levitated by either magnetic forces alone (*Abbott Inc Heartmate 3*) or a combination of magnetic and hydrodynamic forces (*Medtronic Inc. HVAD*). The LVAD inflow is connected to the left ventricular apex and its outflow to the ascending aorta. Electrical power is provided to the implanted pump via a percutaneous driveline cable which is connected to an external controller that receives power from rechargeable batteries or a mains transformer.

Under conditions of a constant pressure gradient across the LVAD and a fixed impeller rotation rate, rotary LVADs generate steady (continuous) blood flow from the left ventricle to the systemic circulation. Normally, however, the left ventricle continues to contract during LVAD support which induces a decrease in the pressure gradient across the LVAD and a corresponding increase in LVAD flow resulting in an attenuated arterial blood pressure pulse. Moreover, contemporary LVADs have algorithms which result in periodic variation of the impeller rotation rate, primarily with the intention of improving the blood flow characteristics within the heart and LVAD in order to counteract the risk of thrombogenesis. This programmed speed variation also affects the arterial blood pressure though typically to a lesser extent than the effect of left ventricular contraction. In combination, these effects result in a unique physiological state of haemodynamic stability with diminished arterial pulsatility. As a consequence, the clinical assessment of an LVAD recipient can be challenging because non-invasive blood pressure, pulse and oxygen saturation may be hard to obtain.

LVAD therapy can confer haemodynamic stability for prolonged periods and technological improvements have reduced the rate of LVAD-associated complications. However, patients undergoing contemporary LVAD therapy remain at unacceptably high risk of life-threatening complications, notably infection, bleeding and stroke²³. As recently as 2017, after one year of LVAD therapy, 93% of patients had an adverse clinical event⁴. When cardiac arrest occurs in LVAD recipients, the mortality rate is over 60%⁵. The combination

of a lack of reliable clinical signs and high risk of complications makes LVAD recipients very vulnerable, particularly if the need for resuscitation arises. Moreover, there is a historical view that cardiopulmonary resuscitation (CPR) is unsafe in LVAD recipients which is not borne out by limited published data^{6,7}. This uncertainty has been shown to both delay the initiation of CPR and limit its application⁸.

Various bespoke LVAD-specific CPR algorithms and protocols have been proposed for use by staff working in advanced heart failure centres⁸⁻¹². International organisations have also included recommendations in society statements and guidelines^{13,14}. All of the proposed models have their merits, yet may vary in their effectiveness according to how well-targeted they are towards staff groups sufficiently skilled to interpret and implement them. In the UK, first responders to in-hospital emergencies are typically bedside nursing staff and junior doctors who may not have adequate experience of dealing with such a complex situation.

Advanced Life Support (ALS) courses and literature provided by the Resuscitation Council UK have protocolised emergency care in non-LVAD patients in a manner which can be readily utilised by these first responders. In this guideline we sought to provide clear guidance for first responders to deteriorating LVAD recipients concerning recognition of arrest, initiation of CPR and key early interventions that can be made to save an LVAD recipient's life.

Scope & Methods

The guideline is designed for staff in advanced heart failure centres in the United Kingdom that manage adult patients with implantable LVADs. Specifically, this relates to emergencies with any of the following implantable LVADs currently in use to treat adults: the *Medtronic Inc HVAD* and *Abbott Inc Heartmate II & III* systems. Existing national guidance is in place for the emergent management of these patients in the outpatient setting primarily for the benefit of ambulance clinicians¹⁵. This guideline is intended to be implemented through the provision of structured training⁸.

We developed this guideline by convening a national LVAD Emergency Algorithm Working Group comprising 13 key UK stakeholder groups: the six advanced heart failure centres where implantable LVADs are implanted: Freeman Hospital, Newcastle, Golden Jubilee National Hospital, Glasgow, Harefield Hospital, London, Royal Papworth Hospital, Cambridge, Wythenshawe Hospital, Manchester and University Hospitals Birmingham. The process was supported by seven national organisations: Association of Cardiothoracic Anaesthesia and Critical Care, British Association of Critical Care Nurses, British Cardiovascular Society, Intensive Care Society, Faculty of Intensive Care Medicine, Resuscitation Council UK, and Society for Cardiothoracic Surgery in Great Britain & Ireland.

The guideline development process complied with the recommendations of the Resuscitation Council UK¹⁶ with grading of evidence according to

European Society of Cardiology¹⁷. Through the working group, we systematically reviewed the evidence base and, using a modified Delphi process, developed consensus by means of majority. The majority was determined through a vote with each advanced heart failure centre and national society assigned one collective vote, with the consortium chair deciding a split vote. The consultation process was initiated in September 2022 with formation of the working group in January 2023. Through electronic communications, virtual meetings and after three modified Delphi rounds, the following guideline was finalised.

UK LVAD Emergency Algorithm development

Key issues were considered sequentially by the working group, as detailed below.

Recommendation	Class	Level
Emergency responders to patients deteriorating and in cardiac arrest with left ventricular assist devices should have dedicated resuscitation training using a structured algorithm.	Ila	C

Initial Response

We recommend placing an immediate cardiac arrest call if any LVAD recipient is found unresponsive and/or not breathing normally. Of course, cardiac arrest calls can also be placed for any deteriorating patient and/or where a staff member is concerned and there are delays in contacting specialist help. In some advanced heart failure centres, activation of an “LVAD cardiac arrest call” will lead to the 24/7 on-call specialist VAD nurse being contacted who can provide prompt expert guidance.

We debated the timing of CPR extensively during the process of design and testing of the algorithm. There are surgical concerns around a risk of anastomotic rupture during chest compressions as the LVAD outflow graft lies in close proximity to the sternum. However, the limited evidence available suggests this risk may have been overestimated particularly in the late post-operative phase⁵⁻⁷. The dominant issue is the fact that contemporary rotary LVADs have a non-occlusive (valve-less) blood path. Thus, when the LVAD stops working, retrograde blood flow can occur from the aorta via the non-functional LVAD, into the left ventricle. The retrograde LVAD flow not only compromises systemic (and hence cerebral) perfusion, particularly if residual left ventricular function is very poor but also limits the efficacy of CPR. However, in spite of these limitations, in the face of persistent LVAD failure, CPR would be expected to augment systemic perfusion, albeit to a limited extent. Thus, we recommend a delay of a maximum of 2 minutes while attempting to restore LVAD function (which is the most effective resuscitative tool available) prior to the initiation of CPR.

Recommendation	Class	Level
In the event of LVAD failure, cardiac arrest CPR may be deferred for a maximum of 2 minutes while immediate interventions are made to restore device function	Ila	C

Initial and secondary responder

If a single responder is present, the priority after calling for help should be to diagnose and promptly treat LVAD dysfunction, if possible. This is equivalent to early CPR in standard ALS. The second responder, who normally will arrive promptly in the hospital setting, should focus on the standard 'Airway' then 'Breathing' approach to patient assessment and attach electrocardiographic monitoring as part of the 'Circulation' step.

Recommendation	Class	Level
The priority in LVAD cardiac arrest is to restore circulation by resolving device dysfunction caused by mechanical failure or physiological problems	Ila	C

LVAD Troubleshooting

The first action of the initial responder, after calling for help, is to review the information displayed on the LVAD controller screen to guide subsequent actions.

Blank Controller: This can be a normal operational state of the *Heartmate 3* LVAD so the initial step is to depress any button on the controller to activate the screen. If the screen of either the *Heartmate 3* or *HVAD* continues to be blank after a button is depressed, the controller is either a) completely depleted of power and requires a battery change, or b) has failed and must be replaced.

High Pump Power (Watts): This can be indicative of the presence of a thrombus within the pump which impinges between the rotating impeller and the pump housing and will require confirmation by blood tests (plasma haemoglobin and lactate dehydrogenase), LVAD log file analysis, and echocardiography. On the basis of these findings, a clinical management plan can subsequently be devised. If the pump thrombosis episode is associated with inadequate circulation, immediate temporary mechanical circulatory support e.g. extracorporeal membrane oxygenation (ECMO) or salvage thrombolytic therapy may be considered.

Driveline disconnection: The percutaneous driveline may have become disconnected and will need to be reconnected to the controller. Alternatively, the driveline may have a modular component (*Heartmate 3*) that has become disconnected. Consequently, exposure of the entire driveline is mandatory to

allow observation of such a disconnection. A third possibility is driveline fracture from mechanical fatigue or damage, which, if detected, should be managed by gentle manipulation to try and restore electrical continuity. If this manoeuvre is successful, the driveline should be immobilised temporarily with adhesive tape. If the driveline is completely severed, there is no simple remedial intervention to restore electrical continuity.

Low or critical battery: This requires replacement of a rechargeable battery with a charged one or connection of the controller to mains power via a transformer.

Low flow alarm: For the *HVAD* and *Heartmate II and 3*, blood flow rate is not directly measured but is estimated using LVAD power consumption and haematocrit. For a given impeller rotation rate, the blood flow generated by the LVAD is inversely proportional to the pressure gradient across the LVAD, i.e. aortic minus left ventricular pressure. Thus, paradoxically, relative hypotension is desirable in LVAD recipients because it is associated with the preservation of adequate LVAD blood flow which not only assures adequate perfusion but minimises the risk of thrombogenesis in the LVAD. This is best achieved through maintenance of mean arterial blood pressure (MAP) in the 60-80 mmHg range. A low LVAD blood flow alarm is likely to be caused by inadequate LVAD filling, the most common cause being hypovolaemia¹⁸ which is frequently attributable to dehydration or more rarely, gastrointestinal bleeding. The primary intervention in response to suspected hypovolaemia should be a passive leg raise, which, if effective, can be followed by cautious intravenous fluid administration (e.g. 4ml/kg) targeting a MAP above 60mmHg¹⁹.

An alternative cause of a low LVAD flow alarm is right ventricular failure, to which further fluid administration could be detrimental. The recognition of right ventricular failure will require historical review of investigations such as echocardiography and right heart catheterisation data. In the immediate setting, echocardiography is likely the most rapid route to diagnostic assessment. If available invasive monitoring such as significantly elevated central venous pressure can also support a volume overloaded state and thus avoidance of fluid.

The low flow alarm can also be activated in response to an excessive LVAD afterload. If the peripheral or invasive MAP >90mmHg and alternative causes of low flow above are assessed and excluded, antihypertensive medication should be administered such as intravenous hydralazine or glyceryl trinitrate.

A rarer cause of low flow is partially occlusive pump thrombosis which normally affects the LVAD inflow. It is managed in a similar manner to pump thrombosis which impinges between the impeller and pump housing resulting in a refractory LVAD power increase.

Arrhythmias can both trigger low flow alarms through reduced preload reaching the left ventricle and be caused by suction of myocardium seen in a low flow alarm.

Recommendation	Class	Level
In an unwell adult patient with “low flow” alarm a passive leg raise should be performed and if responsive a fluid bolus of 250ml or 4ml/kg delivered. Available echo, doppler blood pressure and invasive parameters should be assessed for right ventricular failure and excess afterload where fluid would not be of benefit.	Ila	C

Ventricular arrhythmias: Although ventricular arrhythmias are associated with poor outcomes in LVAD recipients, they may be well tolerated in the short term due to maintenance of perfusion by the LVAD²⁰. This can result in a patient retaining responsiveness in spite of ventricular tachycardia (VT) or ventricular fibrillation (VF). In the presence of an adequate circulation, chemical cardioversion can be attempted in VT. Patients are also likely to have implantable cardioverter defibrillators which can be used to deliver anti-tachycardia pacing. If the VT rate falls below programmed detection boundaries, then the VT zone can be reprogrammed by the pacing team to deliver this therapy.

When electrical cardioversion or defibrillation is being considered sedation must be implemented if patient shows signs of consciousness as is typically the case. Though this may appear to be common sense, there are ongoing occurrences of external shocks being delivered to LVAD patients in VF who have reduced but present consciousness.

If there is inadequate circulation and the patient is unresponsive, then defibrillation should be implemented without delay with three stacked shocks, if required.

Recommendation	Class	Level
In ventricular fibrillation or ventricular tachycardia, defibrillation or cardioversion should be delayed if patient shows any signs of consciousness until sedation can be implemented	I	C

Determination of adequacy of circulation

After LVAD troubleshooting has been attempted, the adequacy of circulation should be confirmed as follows. LVAD patients with a normal circulation will be responsive, not centrally cyanosed, have a normal capillary refill (<3 seconds), MAP >60mmHg¹⁹ and have a normal End Tidal Carbon Dioxide (ETCO₂); which we have defined as being >2kPa in an intubated patient in accordance with other published CPR guidelines¹³. Ultimately, the LVAD should have a normal controller display without active audible and visual alarms, typically with a flow rate >3 litres/min in adults with LVAD humming on chest auscultation.

If there is adequate circulation, staff should undertake a standard 'Airway, Breathing, Circulation, Disability, Exposure' assessment. A persistent reduction in the level of consciousness and/or respiratory arrest in spite of an adequate circulation is strongly suggestive of an acute neurological event, e.g. stroke¹⁹. Patients in a low cardiac output state, with borderline adequacy of circulation should be considered for inotropic infusions to increase intrinsic cardiac output although excessive vasoconstriction should be avoided as an elevated systemic vascular resistance limits LVAD flow.

If circulation remains inadequate, high-level specialist expertise is required. Although the parameters of adequacy of circulation can be assessed, clinical judgement is imperative in the LVAD patient. We chose not to be prescriptive as even potentially reliable parameters, such as ETCO₂, may not be failsafe, for example, in the case of a loose-fitting facemask or laryngeal mask airway. If the patient is within 10 days of LVAD implantation, the Cardiac Advanced Life Support (CALs) algorithm should be followed²¹ with chest reopening, if indicated.

In the absence of a Do Not Attempt Resuscitation (DNAR) order and inadequate circulation, CPR should be started for one of two reasons. The first reason is implementation of a replacement mechanical circulatory support system as a result of unsuccessful attempts to restart the LVAD. Replacement devices include the *Abiomed Inc.* Impella, veno-arterial ECMO or another implantable LVAD. Randomised evidence for emergency ECMO initiation in out-of-hospital cardiac arrest (non-LVAD related) is well established and ECMO flow should be initiated within 60 minutes of arrest onset^{22,23}. Temporary mechanical circulatory support presents technical challenges including retrograde flow through the dysfunctional LVAD which may require outflow graft occlusion with an *Abbott Inc* Amplatzer style device. If the patient is not suitable for another form of mechanical circulatory support, then a second reason to start CPR is to maintain circulation during assessment and treatment of 4Hs (Hypoxia, Hypothermia, Hypovolaemia, Hyper/Hypokalaemia) and 4Ts (Thrombosis, Toxins, Thromboembolism Tension pneumothorax) according to ALS guidance such as thrombolysis for pump thrombosis²⁴.

Mechanical CPR devices are associated with a lack of reliable safety data in LVAD recipients²⁵. However pragmatically they have a demonstrated role in prolonged cardiac arrest and during the institution of emergency ECMO.

Echocardiography can be of utility in determining the cause of cardiac arrest, such as right ventricular failure, suction events, tamponade, or intracardiac thrombus. However, it is reliant on a competent sonographer being available at the time of the emergency and acoustic windows may be limited. Thrombus within the LVAD pump housing cannot be visualised by echocardiography and so this remains an adjunctive investigation in our algorithm rather than a treatment-determining criteria.

Recommendation	Class	Level
----------------	-------	-------

Assessment of adequate circulation should be made utilising a number of physiological parameters and not pulse alone.	Ila	C
---	-----	---

Recommendation	Class	Level
CPR can be performed safely in LVAD patients with inadequate circulation	I	C

Recommendation	Class	Level
The use of mechanical CPR devices in LVAD patients is lacking safety data and should only be utilised in refractory arrests and to facilitate emergency ECMO insertion.	Ila	C

Recommendation	Class	Level
In the presence of inadequate circulation in a LVAD patient less than 10 days post LVAD implantation, emergent chest re-opening should be performed if initial measures have failed.	Ila	C

Recommendation	Class	Level
In the presence of inadequate circulation immediate escalation to temporary mechanical support such as ECMO should be considered and initiated within 60 minutes.	Ila	C

Conclusion

Figure 1 illustrates the output from this initiative, i.e. an implantable LVAD-specific resuscitation guideline for in hospital use in specialist advanced cardiac centres. This guideline is intended to be implemented in combination with a structured training programme.

References

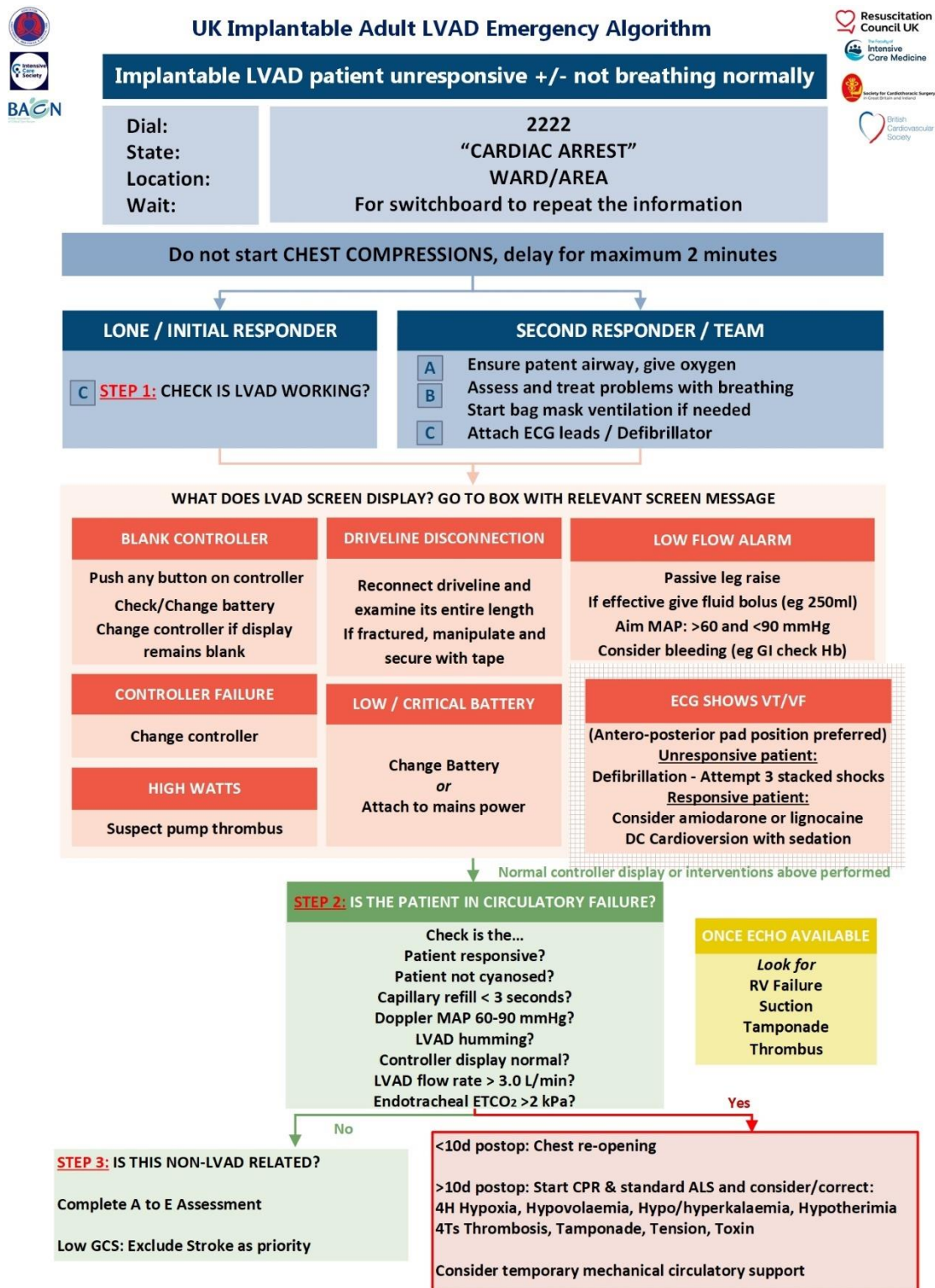
1. Parameshwar J, Hogg R, Rushton S, et al. Patient survival and therapeutic outcome in the UK bridge to transplant left ventricular assist device population. *Heart*. 2019;105(4):291-296. doi:10.1136/HEARTJNL-2018-313355
2. Mehra MR, Uriel N, Naka Y, et al. A Fully Magnetically Levitated Left Ventricular Assist Device - Final Report. *N Engl J Med*. 2019;380(17):1618-1627. doi:10.1056/NEJMOA1900486
3. Kirklin JK, Naftel DC, Kormos RL, et al. Fifth INTERMACS annual report: risk factor analysis from more than 6,000 mechanical circulatory support patients. *J Heart Lung Transplant*. 2013;32(2):141-156. doi:10.1016/J.HEALUN.2012.12.004
4. Lohmueller LC, Movahedi FA, Antaki JF. Living the Dream: Event Free Survival in Patients Receiving a Cf-LVAD. *J Card Fail*. 2017;23(8):S118. doi:10.1016/j.cardfail.2017.07.347
5. Barssoum K, Patel H, Rai D, et al. Outcomes of Cardiac Arrest and Cardiopulmonary Resuscitation in Patients With Left Ventricular Assist Device; an Insight From a National Inpatient Sample. *Heart Lung Circ*. 2022;31(2):246-254. doi:10.1016/J.HLC.2021.05.096
6. Mabvuure NT, Rodrigues JN. External cardiac compression during cardiopulmonary resuscitation of patients with left ventricular assist devices. *Interact Cardiovasc Thorac Surg*. 2014;19(2):286-289. doi:10.1093/ICVTS/IVU117
7. Shinar Z, Bellezzo J, Stahovich M, Cheskes S, Chillcott S, Dembitsky W. Chest compressions may be safe in arresting patients with left ventricular assist devices (LVADs). *Resuscitation*. 2014;85(5):702-704. doi:10.1016/J.RESUSCITATION.2014.01.003
8. Akhtar W, Gamble B, Kiff K, et al. Mechanical life support algorithm developed by simulation for inpatient emergency management of recipients of implantable left ventricular assist devices. *Resusc Plus*. 2022;10. doi:10.1016/J.RESPLU.2022.100254
9. Yuzefpolskaya M, Uriel N, Flannery M, et al. Advanced cardiovascular life support algorithm for the management of the hospitalized unresponsive patient on continuous flow left ventricular assist device support outside the intensive care unit. *Eur Heart J Acute Cardiovasc Care*. 2016;5(8):522-526. doi:10.1177/2048872615574107
10. Garg S, Ayers CR, Fitzsimmons C, et al. In-hospital cardiopulmonary arrests in patients with left ventricular assist devices. *J Card Fail*. 2014;20(12):899-904. doi:10.1016/J.CARDFAIL.2014.10.007
11. Haglund NA, Schlendorf K, Keebler M, et al. Is a palpable pulse always restored during cardiopulmonary resuscitation in a patient with a left ventricular assist device? *Am J Med Sci*. 2014;347(4):322-327. doi:10.1097/MAJ.0000000000000219
12. Garg S, Ayers CR, Fitzsimmons C, et al. In-Hospital Cardiopulmonary Arrests in Patients With Left Ventricular Assist Devices. *J Card Fail*. 2014;20(12):899-904. doi:10.1016/J.CARDFAIL.2014.10.007

13. Cook JL, Colvin M, Francis GS, et al. Recommendations for the Use of Mechanical Circulatory Support: Ambulatory and Community Patient Care: A Scientific Statement From the American Heart Association. *Circulation*. 2017;135(25):e1145-e1158. doi:10.1161/CIR.0000000000000507
14. Saeed D, Feldman D, Banayosy A El, et al. The 2023 International Society for Heart and Lung Transplantation Guidelines for Mechanical Circulatory Support: A 10- Year Update. *Journal of Heart and Lung Transplantation*. 2023;42(7):e1-e222. doi:10.1016/j.healun.2022.12.004
15. Bowles CT, Hards R, Wrightson N, et al. Algorithms to guide ambulance clinicians in the management of emergencies in patients with implanted rotary left ventricular assist devices. *Emergency Medicine Journal*. 2017;34(12):842-850. doi:10.1136/EMERMED-2016-206172
16. Soar J, Mitchell S, Gwinnutt C, Bullock I, Cummin V. *Guidelines Development Process Manual*.; 2021. Accessed July 2, 2023. https://www.resus.org.uk/sites/default/files/2021-04/RCUK%20Process%20Manual%202021_0.pdf
17. European Society of Cardiology. *Governing Policies and Procedures for the Writing of ESC Clinical Practice Guidelines*.; 2017. Accessed July 2, 2023. <https://www.escardio.org/static-file/Escardio/Guidelines/About/Recommendations-Guidelines-Production.pdf>
18. Ogami T, Naka Y, Sanchez J, et al. Incidence and Cause of Persistent Low Flow Alarm after HeartMate 3 Left Ventricular Assist Device Insertion. *The Journal of Heart and Lung Transplantation*. 2020;39(4):S404. doi:10.1016/j.healun.2020.01.152
19. Saeed O, Jermyn R, Kargoli F, et al. Blood pressure and adverse events during continuous flow left ventricular assist device support. *Circ Heart Fail*. 2015;8(3):551-556. doi:10.1161/CIRCHEARTFAILURE.114.002000
20. Nakahara S, Chien C, Gelow J, et al. Ventricular arrhythmias after left ventricular assist device. *Circ Arrhythm Electrophysiol*. 2013;6(3):648-654. doi:10.1161/CIRCEP.113.000113
21. Lizotte D. *Cardiac Advanced Resuscitation Education*. CSU ALS; 2021.
22. Yannopoulos D, Bartos J, Raveendran G, et al. Advanced reperfusion strategies for patients with out-of-hospital cardiac arrest and refractory ventricular fibrillation (ARREST): a phase 2, single centre, open-label, randomised controlled trial. *The Lancet*. 2020;396(10265):1807-1816. doi:10.1016/S0140-6736(20)32338-2
23. Belohlavek J, Kucera K, Jarkovsky J, et al. Hyperinvasive approach to out-of hospital cardiac arrest using mechanical chest compression device, prehospital intraarrest cooling, extracorporeal life support and early invasive assessment compared to standard of care. A randomized parallel groups comparative study proposal. "Prague OHCA study." *J Transl Med*. 2012;10(1). doi:10.1186/1479-5876-10-163
24. Council Resuscitation. *Advanced Life Support Algorithm*.; 2021.
25. Miyashita S, Ortoleva J, Vest A, Couper G, Kawabori M. (813) Prolonged Cardiopulmonary Resuscitation with Lucas Device in a Patient with Left Ventricular Assist Device. *The Journal of Heart and Lung Transplantation*. 2023;42(7):e1-e222. doi:10.1016/j.healun.2022.12.004

Lung Transplantation. 2023;42(4):S356.
doi:10.1016/J.HEALUN.2023.02.826

DRAFT

Figure 1: UK LVAD Emergency Algorithm



LVAD left ventricular assist device, ECG electrocardiograph, MAP mean arterial pressure, GI gastrointestinal, Hb haemoglobin, DC direct current, ET CO₂ end-tidal carbon dioxide, A to E Airway to Exposure, GCS Glasgow coma score, CPR cardiopulmonary resuscitation, ALS advanced life support