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Development and Simulation-Based Validation of a Mechanical Life Support Algorithm for Inpatient LVAD Emergencies

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Abstract

Existing recommendations for handling acute emergencies in patients supported by left ventricular assist devices (LVADs) remain sparse and often contradictory, contributing to hesitation or errors during time-critical situations. In our high-volume tertiary LVAD centre, we designed and refined a new, streamlined resuscitation protocol tailored to in-hospital LVAD crises. The protocol was tested and optimised using realistic simulation sessions with input from the full multidisciplinary team. We then launched a dedicated "Mechanical Life Support" training programme that blended didactic teaching, practical skills stations, and scenario-based simulation to build both competence and confidence. Effectiveness was evaluated through pre- and post-training confidence ratings, a critical performance measure (time required to restore pump flow), and a formal knowledge test. Before any intervention, staff rated their confidence in managing LVAD emergencies at just 2.4 ± 1.2 out of 5. After targeted simulation training, this improved to 3.5 ± 0.8. With the new protocol in place, the average time taken to re-establish LVAD flow dropped dramatically from 49 ± 8.2 seconds to 20.4 ± 5 seconds ($p < 0.0001$). Participants completing the full Mechanical Life Support course reported confidence rising from 2.5 ± 1.2 to 4.0 ± 0.6 ($p < 0.0001$), while knowledge-test scores increased from 18.7 ± 3.4 to 22.8 ± 2.6 out of 28 ($p < 0.0001$). This work introduces an easy-to-follow, LVAD-specific advanced life support algorithm aimed at optimising those vital first few minutes of resuscitation when rapid, basic actions can significantly improve survival and neurological outcome.

Keywords: LVAD, Mechanical circulatory support, Cardiac arrest, Resuscitation algorithm, Emergency training, Simulation

Introduction

In the UK, adult treatment with left ventricular assist devices (LVADs; **Figure 1**) is provided through a specialised national programme based at six heart-transplant centres. These devices are used either to maintain circulation while patients await a transplant or to support recovery of the native left ventricle [1].

An internal audit reported that, by August 2020, 314 adults in the UK were living with an LVAD. Although the number of recipients is modest, the clinical burden associated with LVAD therapy is substantial [2, 3], and repeat hospital admissions are common.

Even with the improvements offered by current-generation pumps, serious complications remain frequent. Within a year after implantation, as many as 70% of individuals experience significant adverse events—ranging from pump malfunction and thrombotic obstruction to bleeding, infections, or neurological injury [4].

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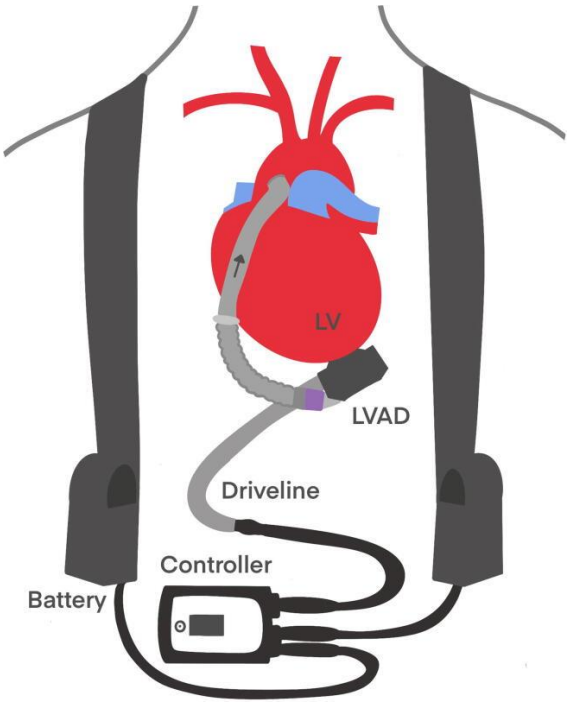

Figure 1. Schematic of left ventricular assist device design, LV: Left ventricle, LVAD: Left ventricular assist device

Because LVAD therapy has distinct mechanical and physiological characteristics, many rotating or newly appointed staff in specialist units have limited exposure to emergencies involving these devices. Structured algorithms can help deliver a rapid, consistent, and systematic response during resuscitation [5]. Yet, the amount of published in-hospital guidance for LVAD emergencies remains small, and existing recommendations often diverge from standard advanced life-support procedures. This lack of alignment increases the likelihood of hesitation, errors, and suboptimal outcomes [6–10].

Clinical assessment is also complicated in LVAD recipients. These patients often have no palpable pulse, and auscultation is dominated by the continuous 'hum' produced by the device. Conventional monitoring—such as non-invasive blood pressure measurement or pulse oximetry—frequently fails to provide reliable readings [9], removing cues clinicians typically use to identify cardiac arrest. Furthermore, LVAD flow is influenced by several interacting factors, including pump speed, venous return, intrinsic myocardial function, and vascular tone, making physical assessment difficult, particularly during haemodynamic instability. Controversy persists regarding when chest compressions are appropriate in LVAD patients, and this uncertainty can delay more effective interventions during cardiovascular collapse.

Our group has previously created emergency algorithms for pre-hospital clinicians managing LVAD patients in the community [2]. These guidelines, endorsed by the Resuscitation Council UK and the Joint Royal Colleges Ambulance Liaison Committee, are now used nationally. The present initiative seeks to extend this structured approach into the hospital setting so that deteriorating inpatients with LVADs receive an appropriate, device-specific response.

Materials and Methods

This work was undertaken between January and October 2021 at Harefield Hospital, London, a tertiary centre specialising in advanced heart-failure care, including transplantation and LVAD therapy, serving a network of 78 hospitals [11]. Most patients in our centre who would benefit from the new resuscitation guidance are supported with either the Medtronic (formerly HeartWare) HVAD or the Abbott HeartMate 3.

We began by performing a one-day internal audit to evaluate how confident healthcare staff—both inpatient and outpatient—felt when managing LVAD-related emergencies. Confidence was rated using a five-point Likert scale (1 = not confident at all; 5 = very confident).

Ward-Based simulation

Participants, simulation equipment, and setting

We implemented a programme of ward-level simulation exercises for staff, using the previously published out-of-hospital LVAD emergency algorithm [2]. These sessions involved personnel scheduled for duty on the transplant ward. Each scenario was run by three facilitators—one coordinating the exercise, one operating the LVAD and generating alarm conditions, and one managing the patient's vital signs.

A Laerdal Resusci Anne full-body manikin with SimPad was used, alongside a standard in-hospital resuscitation trolley stocked with airway, breathing, and circulatory equipment, including a defibrillator. Additionally, we developed a custom LVAD training model consisting of an LVAD and a sealed container that recirculates water. By clamping the tubing, reduced flow can be reproduced. The device is connected to a standard controller and battery pack and placed next to the manikin during training. Before beginning each scenario, participants were given a briefing with particular emphasis on defibrillation safety.

Scenario construction

A broad range of clinical problems was rehearsed, including driveline disconnection, loss of electrical power, low-flow alarms, arrhythmias, haemorrhage, sepsis, and intracranial bleeding. Teams of three were assigned to each scenario, comprising a designated team leader and two responders. Leaders were encouraged to position themselves at the end of the bed, keep the algorithm in hand, and issue step-wise instructions. Responders communicated their findings—such as controller alarm messages—back to the leader, who directed subsequent actions. Most sessions involved two scenarios lasting 5–10 minutes each, followed by approximately 5 minutes of structured feedback.

Feedback process

After each exercise, both participants and observers were asked to reflect on what had gone well and what could be improved. The facilitators also reviewed the underlying physiology and clinical management relevant to each case. Upon leaving, participants completed an anonymous online questionnaire that included a confidence rating for each scenario, using the previously described scoring system.

Development of the in-hospital algorithm

Simulation exercises highlighted several components of the pre-hospital algorithm that required adjustment for hospital use. A multidisciplinary working group—with representation from cardiology, transplant surgery, intensive care, nursing, and resuscitation services—was convened to create an in-hospital LVAD resuscitation pathway. Through repeated testing and revision, the algorithm was refined until it was judged safe and practical **(Figure 2)**.

A key performance measure was also defined: the interval required for staff to identify and correct a driveline disconnection. The initial steps of the algorithm emphasise fast recognition of LVAD malfunction and prompt corrective actions based on the controller's alarm messages. The completed algorithm was introduced to all clinical teams via the governance programme and formally approved in July 2021. Laminated versions were subsequently placed on every cardiac-arrest trolley and displayed at the bedside of all admitted LVAD recipients.

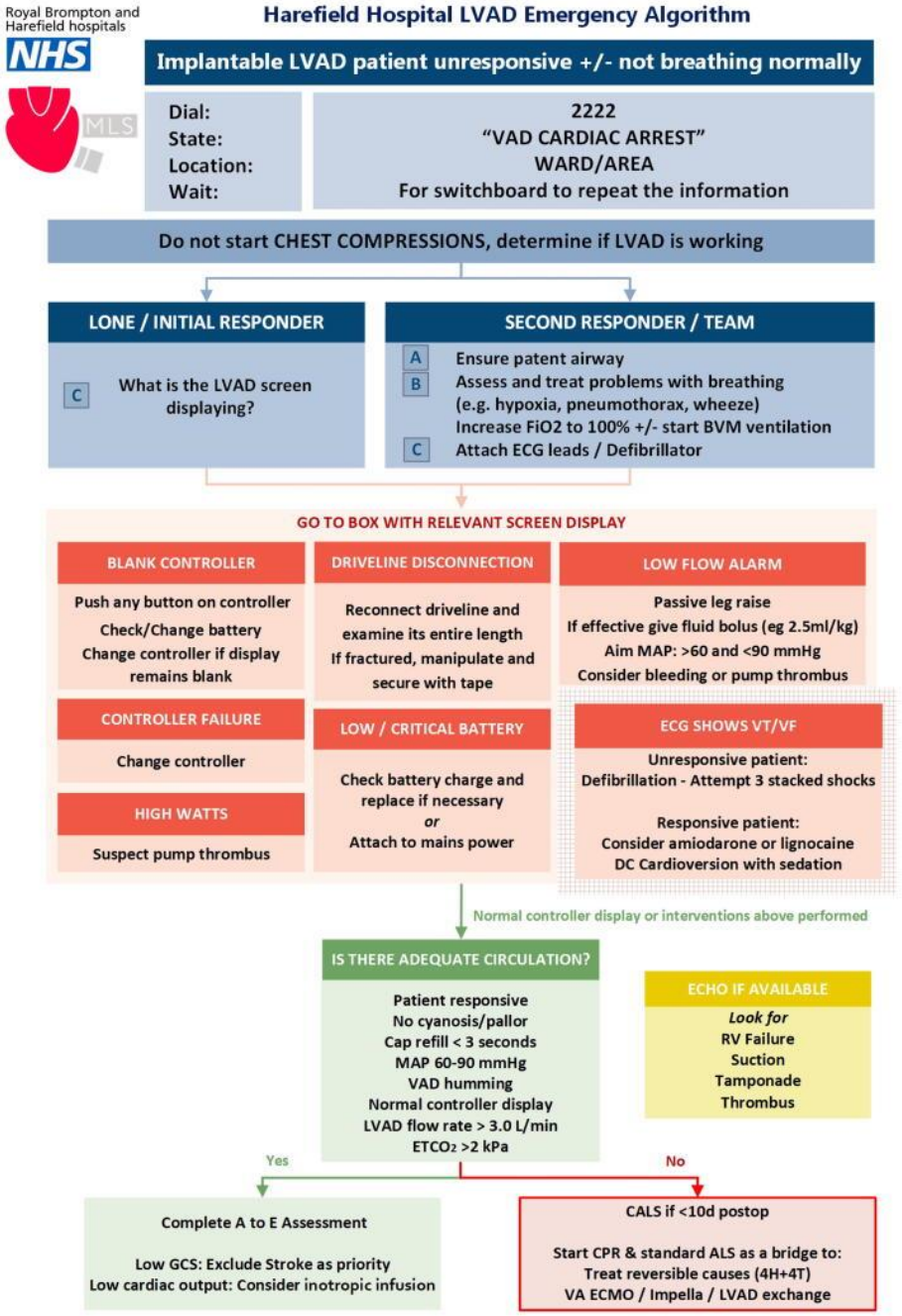

Figure 2. Left ventricular assist device in-hospital resuscitation algorithm. Abbreviations: LVAD – Left Ventricular Assist Device; FiO_2 – Fraction of Inspired Oxygen; BVM – Bag-Valve Mask; ECG – Electrocardiography; MAP – Mean Arterial Pressure; DC – Direct Current; $ETCO_2$ – End-Tidal Carbon Dioxide; A–E – Airway to Exposure; GCS – Glasgow Coma Scale; CALS – Cardiac Advanced Life Support; CPR – Cardiopulmonary Resuscitation; ALS – Advanced Life Support; 4H & 4T – Hypoxia, Hypokalaemia, Hyperkalaemia, Hypothermia, Hyperthermia, Hypovolaemia & Tension Pneumothorax, Tamponade, Thrombosis, Toxins; VA-ECMO – Veno-Arterial Extracorporeal Membrane Oxygenation

Mechanical Life Support © Course

The in-hospital algorithm was designed to support frontline staff during early troubleshooting and is structured around complications commonly seen in clinical practice. Its use assumes basic familiarity with LVAD components—including electrical connectors and expected operating values. To build this foundational knowledge, we delivered a half-day Mechanical Life Support course aimed at participants with little or no prior LVAD experience.

Participants, course structure, simulation setup

The course was open to all hospital staff, and each session enrolled ten candidates from nursing, medical, and allied health professions. Participant experience varied widely, from daily involvement with LVAD patients to no previous contact at all. Training took place in the hospital's simulation centre and used the same equipment as the ward-based scenarios. Before attending, candidates received the newly developed algorithm and the published guidance on LVAD resuscitation [2].

Teaching began with lectures covering advanced heart failure, temporary and durable mechanical circulatory support, and cardiac transplantation. This was followed by a practical skills session in which candidates learned to disconnect and reconnect external LVAD components, and to safely carry out controller and battery exchanges under supervision from LVAD specialist nurses.

Participants then engaged in multiple simulated emergency scenarios—similar to those used in the ward-based programme—to practise applying the algorithm in real time. The final part of the course consisted of focused skill-stations on brachial arterial Doppler blood pressure measurement, interpretation of LVAD parameters, $ETCO_2$ monitoring, basic echocardiography recognition, and principles of right-ventricular management.

Feedback and assessment

Candidates completed pre- and post-course multiple-choice assessments and were continuously observed during the practical sessions to determine whether they had achieved the required competency. Individuals needing additional support were offered one-to-one teaching beyond the scheduled course. Course effectiveness was evaluated by comparing changes in self-reported confidence scores (as described earlier) and performance on the emergency-scenario MCQ examination.

Statistical analysis

Continuous variables are expressed as mean ± standard deviation. Pre- and post-training values were compared using paired t-tests or the Wilcoxon signed-rank test, depending on distribution. Differences in means were calculated directly; for the signed-rank test, the Hodges–Lehmann estimator was used to determine the median difference. All tests were two-sided, with statistical significance defined as $p < 0.05$. Analyses were performed using Stata version 17 (StataCorp LLC, Texas).

Results and Discussion

Baseline assessment showed that doctors, nurses, and allied health professionals in the transplant service reported low confidence in dealing with LVAD emergencies, with a mean score of 2.4 ± 1.2 out of 5 (n = 29) [1].

Eight ward-based simulation sessions were delivered using the out-of-hospital algorithm, involving 47 multidisciplinary staff members. Among participants who submitted evaluations, confidence improved to a mean of 3.5 ± 0.8 (n = 13) following the sessions [1].

Introducing the revised in-hospital algorithm resulted in a marked reduction in the time required to restart an LVAD: from a pre-training mean of 49 ± 8.2 seconds to 20.4 ± 5 seconds after training (n = 42, $p < 0.0001$) [2].

After roll-out of the Mechanical Life Support course to 44 staff members, confidence scores rose from 2.5 ± 1.2 to 4 ± 0.6 ($p < 0.0001$). Knowledge scores on the MCQ assessment also increased significantly—from 18.7 ± 3.4 to 22.8 ± 2.6 out of 28 ($p < 0.0001$) [3].

Deterioration in patients supported by LVADs can be difficult for clinical teams to manage, particularly when early responders have limited prior exposure to such events. Our evaluation demonstrated that staff initially felt under-prepared for LVAD-related emergencies [1]. To mitigate this risk, we developed a combined strategy incorporating simulation, algorithm refinement, and focused teaching that aligned with contemporary resuscitation principles [2].

Existing algorithms were modified for in-hospital use through repeated simulation cycles and detailed multidisciplinary input [2]. Across these reviews, a consistent message emerged: rapid identification and correction of LVAD malfunction is essential for favourable outcomes. Consequently, the revised algorithm prioritised swift troubleshooting and provided clearer instructions on evaluating perfusion and determining when CPR is appropriate—an area that frequently generates uncertainty among frontline staff [2].

The resulting Mechanical Life Support programme produced marked gains in staff capability, reflected in both self-reported confidence and objective knowledge assessments [3]. Importantly, a novel performance measure—the speed at which personnel identified and corrected driveline disconnection—also improved significantly, indicating a meaningful translation of training into practical skill [2**]**.

Discussion (Rewritten)

The component of the algorithm that generated the greatest debate was the role, timing, and potential benefit of CPR in patients supported with an LVAD. Although CPR has traditionally raised concerns—particularly the possibility of disrupting surgical anastomoses—the limited data available indicate that this complication may be

rarer than previously assumed, especially in patients whose devices have been in place for a longer period [2, 9]. Because blood can move retrogradely through a non-occlusive, valve-less LVAD circuit during device failure, chest compressions may be less effective. However, in circumstances where neither the native heart nor the LVAD is providing circulation, CPR is unlikely to worsen the situation and may offer a temporary means of supporting perfusion.

Our previous work has recommended reserving CPR for two situations: (a) as a short-term measure while attempts are made to restore LVAD function, or (b) when all other options are exhausted—an approach consistent with the American Heart Association guidance, which prioritises re-establishing LVAD support [2, 9]. If efforts to restart the device are unsuccessful, initiating CPR as a bridge to further interventions, such as temporary circulatory support or therapies like thrombolysis, is a reasonable consideration.

This project has limitations, including its single-centre nature and the ongoing scarcity of high-level evidence to guide advanced life support protocols in LVAD-related emergencies. Until more robust clinical data are available, we suggest that practice informed by accumulated experience and iterative simulation remains the most pragmatic strategy.

Conclusion

LVADs introduce unique physiological considerations and device-specific risks, which can make emergency care challenging—particularly for early responders who often have limited prior exposure to these patients. We offer a streamlined VAD Advanced Life Support algorithm designed to support clinicians during the critical initial phase of resuscitation, where timely, straightforward actions may substantially influence patient outcomes.

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