



Donor Organ Utilisation Efficiency in LVAD Bridge-to-Transplant Versus Direct Heart Transplant

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Abstract

Heart transplantation is a significant surgical intervention with a scarcity of donated organs constituting one of the biggest challenges registering high risk that informed the need to develop means of increasing utilisation of the available organs while fostering patients' positive outcomes. As a bridge-to-transplant, LVADs are commonly used. Restoring Direct heart transplantation is the other option where suitable organs are available immediately. The setting, comparative efficiency and outcomes of such strategies thus warrant further study to inform clinical practice and policies. In turn, this meta-analysis sought to assess the donor organ utilisation efficiency, post-LVAD BTT, direct HT recipient survivability, and medical complication profiles. The goal was to recognise each patient's strengths and flaws to enhance their use in clinical activities and resource management. The databases PubMed, Embase and Cochrane Library were searched to screen the literature systematically regarding the comparison of the two strategies. Data extraction focused on key outcomes: institutional donor organ acceptance rates, posttransplantation survival rates, time to transplantation, and perioperative complication. Post hoc comparisons were carried out to examine the heterogeneity and conclusiveness of the resulting data. The review concluded decreased late survival for each plan while the ten-year survival analysis was equal. Patients getting an LVAD had relatively better preoperative profiles but higher pre-transplant morbidity of infection and LVAD-related complications, as well as longer waiting times. Living donor recipients experienced fewer complications before transplantation surgery, but newer issues included ischemic injury and complexity in the allocation of grafts. We found that there was higher donor organ wastage in the LVAD group because of the long waiting period and the complications that come with it. The present meta-analysis compares both strategies' effectiveness while shedding light on their challenges. Better allocation of the organ, better management of the LVAD, and targeted treatment trajectories are needed to show beneficial results. These conclusions require interprofessional interaction between clinicians, policymakers, and researchers to improve transplantation processes and respond to organ deficiencies.

Introduction

Heart transplantation has been the official treatment for patients with end-stage heart failure. It affords hope of a cure for those suffering from the condition as they lack other medical and surgical ambitions [1]. However, heart transplantation, although very effective in the treatment of end-stage

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heart diseases, has been hindered by the shortage of donor organs, which is a significant drawback among transplant disciplines. A recent study has also revealed that the waiting list of patients with end-stage heart failure has increased over the years even as the availability of a suitable matching donor heart has remained a challenge, therefore increasing the waiting time and number of deaths among patients, waiting for a suitable organ to be transplanted into their hearts [1].

The chief limit factors affecting the availability of donor hearts include scarce availability of donor organs, strict criteria used in qualifying donors, and growing demand for transplants due to a growing ageing population and increasing rate of incidence of heart failure. Therefore, a significant number of patients stay one or more years waiting to access these services, and this causes their conditions to worsen; some develop complications that may lead to organ dysfunction and even death due to heart failure. These challenges have, however, met with innovative ways to get organs that best meet the requirements of the patients. One of these strategies, which has received much limelight in the recent past, is the application of LVADs in patients as a bridge to transplant [2].

LVADs refer to mechanical devices which function as auxiliaries over the natural human heart, explicitly pumping blood throughout the rest of our body. They are primarily implemented in cases with end-stage heart failure, especially those patients who can't receive a heart transplant right away because of the shortage of appropriate grafts. Because LVADs do not replace the function of the right ventricle, the heart's auxiliary pumping chamber, but take up the job of the heart's main pumping chamber, the left chamber, LVADs facilitate systemic circulation until a human-compatible heart is found. This is particularly significant because the utilisation of LVADs in the management of patients awaiting heart transplantation has successfully supplanted traditional methods [3] of providing interim support for patients in end-stage heart failure waiting for a heart transplant [3].

LVADs have been proven in years past to enhance survival, quality of life and functional capacity for patients, who otherwise have the only options of dying or being morbid. This gadget has now been used routinely for patients with end-stage heart failure, especially patients with significant heart disease who are still too frail to pump adequately but do not yet meet the criteria for a heart transplant.

Nonetheless, there are several issues which remain concerning the therapy that involves LVAD implantation [4]. The use of LVADs has significant benefits on the clinical status of patients with heart failure. However, LVAD therapy has a list of associated complications. These are infection, bleeding, thromboembolic events and malfunctioning of the implanted device. Moreover, the subject of long-term LVAD use is not Mathews, and Strueber does not address the

question of the shortage of donor organs; somewhat, it only hides the problem and merely steps the individual closer to requiring a heart transplant [5]. This means that many patients with LVADs may stay longer waiting for a donor organ and, during this time, suffer other related complications. Hence, even as LVADs are a critical approach to transplant planning, they cannot address the issue of scarce organs.

Copeland et al. [6] demonstrated that On the other hand, direct heart transplantation remains an acceptable mode of therapy for patients who are eligible for this procedure and in whom a donor's heart is easily obtainable. However, direct heart transplantation also has its advantages and, of course, disadvantages. The main issue with direct heart transplantation is the selection of the patients who should be transplanted. A few patients in need of a transplant are elderly, sick, or have other diseases, which make them unlikely candidates for the transplant. Besides, some risks are connected with the surgery: infection, graft rejection, and immunosuppression complications.

In addition, the timing of the transplant is critical in the process because delayed or rushed surgeries negatively affect patient results. In some cases, the donor heart may not be transplanted to the recipient's body in time; this results in ischemic injury, which subsequently affects the functionality of an organ once it has been transplanted, thus deeming the patient's survival chances shorter. Secondly, there is no simple decision that is arrived at on which specific patients should be transplanted with the heart and when, and it involves a balance between the types of risks the patient can take without compromising the quality of life, the availability and appropriateness of the donor's heart among other factors [7].

Recent additions to LVADBridge to Transplant experience indicate a redesigned focus on the effectiveness of LVAD compared to direct heart transplantation, utilising the donor organs more efficiently. The use of donor hearts has advantages and limitations, such as the central question of this present research of how the shortages of organs can best be addressed [8]. Several researchers have claimed that the use of LVAD can assist in preparing the status of patients requiring heart transplantation; there may be better transplant results and increased health system productivity of heart organs. Some have expressed this view by saying that dangers linked with LVAD therapy lower the general advantage based on this strategy [9].

These shortcomings were addressed by meta-analysis by combining results from several studies to give the overall outcomes of LVAD bridge-to-transplant strategies compared to direct heart transplantation. Such studies have provided a better understanding of the differential efficacy of the two methods: mortality, morbidity and late prognosis [10]. For instance, researchers have pointed out that those patients who

received LVADs and await transplant have equivalent, if not superior, prognosis to the transplanted hearts, primarily if the underlying condition of the patient is maintained at the optimal level when awaiting the transplant. In contrast, other works have pointed out the dangers of having LVADs, such as device-related complications, and others have found out that the option of direct heart transplantation appears to offer superior short-term results for particular patient groups.

Based on current and future difficulties in the availability of donor organs and the attempts to improve the efficiency of their usage, it is essential to gain knowledge of these two approaches' comparative strengths and weaknesses. A meta-analysis can be of considerable significance in understanding how to distribute scarce resources such as donor hearts, which would reduce the death-risk of all patients while also dealing with the question of supply. Such an analysis carried out by systematically reviewing and synthesising the available evidence can thus support clinical practice and decision-making within the field of heart transplantation [11].

Therefore, heart transplantation remains the gold standard for the treatment of patients with end-stage heart failure. However, limited donor hearts persist [12]. They have grown into a central planning for having patients with LVADs wait for transplantation. However, LVAD therapy is not without its difficulties and complications and the use of direct heart transplantation is also constrained by complications, issues regarding patient selection, as well as concerns regarding the effectiveness of donor organ usage. It is also an area of further research that could counsel practice in identifying the practicable comparative advantage of these strategies, especially about issues of donor organ shortage. Additional understanding might be achieved through meta-analysis of the literature on heart transplantation to understand better the existing structure and how to offer maximal application of scarce donor organs [13].

An increasingly common phenomenon such as heart failure, along with the constant increase in the number of individuals of the older generation, only exacerbates the lack of donor organs. Due to improved medical processes, people with heart failure are living longer, but the number of patients who can receive transplants still increases. However, restrictions have caused a lack of increase in the supply of donor hearts. Several donor organs, donating organs issues, and factors related to the preservation and transportation of organs [14]. This situation is evidenced by a growing gap in the relationship between heart transplant recipients and transplanted hearts with scaled waiting time and, consequently, higher mortality rates among patients waiting for a transplant. These challenges have created strategies to maximise the effectiveness of donor organs, such as LVADs-mechanical circulatory support devices.

A left ventricular assist device is an essential therapy for advanced heart failure patients, especially for those waiting

to transplanted from a lack of donor organs. The devices are predominantly used in the bridge-to-transplant, which involves using the device to supplement heart function until a suitable donor organ is sourced. Besides increasing the survival rates of a patient, LVADs also facilitate functional rehabilitation of the patient, allowing the patient to lead an improved life while waiting for a transplant. However, LVADs have problems involving infection, formation of blood clots, and other issues due to the non-functioning of the device. Additionally, there are long-term effects of LVADs that may include pump thrombosis, gastrointestinal bleeding, and stroke [15]. These risks, coupled with the fact that many patients require quite a long time before they can get a donor organ, make LVADs a less efficient bridge strategy [15].

The feasibility of LVAD and direct heart transplant strategies also depends on several countable factors, including the health status of the patient and the existence or otherwise of other diseases, in addition to the quality of the donor's heart. Such aspects highlight the importance of choosing between the two approaches since it involves the risks and returns of the valuable patients regarding the best approach [14]. The distribution of donor organs continues to be a considerable debate, with no clear solution to the question of the most optimal, effective, and fair allocation of this scarce value.

The effective use of donor organs has remained an essential question in transplant medicine, where employing LVADs as a bridge to transplantation or directly giving heart transplants has been a significant concern. Although LVADs have offered a workable strategy for the management of patients with end-stage heart failure while awaiting a suitable donor, some of the risks associated with the devices, such as infection, bleeding and device failure, are now in doubt in terms of their effects on transplant success rate and utilisation of health resources. Direct heart transplantation as the gold standard for heart replacement when a donor's heart is readily available has been fraught with issues such as availability and timely procurement of the donor organ requisite organ preservation techniques, which at times has led to missed chances or subpar outcomes. Such disparity of strategies has brought about an imperative of benchmarking the effectiveness of donor organ use and distribution to serve and maximise the lot where scarcity prevails, and CA survival and quality of life are at stake.

Methods

Study Design

This study conducted a meta-analysis to critically and comparatively analyse the donor organ usage in LVAD BTT and direct heart transplantation. Meta-analysis is a quantitative synthesis that uses data from independent studies to arrive at an overall conclusion of the body of research. As demonstrated in this method, this approach enhances

statistical capacity, amplifies strengths, reduces bias, and enables the assessment of trends or patterns that are difficult to identify using individual work.

A specific approach of study selection was used based on the medical databases such as PubMed, Scopus, and Cochrane Library. Predominantly, the inclusion criteria for the selection of literature involved a direct comparison of LVAD BTT and direct transplantation programs and their outcomes in terms of donor organ use, patient survival, and complications. Both cross-sectional and case-control studies were included, while the history cohort and other types of case-control studies were included if they met both quality and relevance criteria. Limitation criteria comprised case reports, studies with insufficient data, and those not pertinent to the objectives.

Data extraction comprised essential patient characteristics, treatment results, waiting time, organ supply, and transplant success rate. The synthesis applied advanced statistical techniques to estimate and compare the pooled magnitude of effect, odds ratio, and confidence interval. To reduce heterogeneity across the compared studies, subgroup analysis and sensitivity analysis were performed, proving the accuracy and soundness of the results. This approach gave a strong idea compared to the efficiency of the two transplant strategies.

Search Strategy

The search strategy was developed to locate the articles that compare the use of donor organs and the efficiency of LVAD as a bridge-to-transplantation and direct heart transplantation. These databases were chosen because they provided the most comprehensive coverage of peer-reviewed medical and clinical literature in PubMed, Embase, and Cochrane Library. The following approach was observed to increase the quality and relevance of the selected literature.

The present articles were only selected after using keywords and Boolean operators to search and pick all articles relative to the subject. Strong search terms were "LVAD", "Left Ventricular Assist Device", "heart transplantation", "direct transplant", "bridge to transplant", and "donor organ utilisation". Specific connectors such as AND, OR, and NOT were used, whereby only AND and OR operators made the search more precise. For instance, the following search terms were used: (LVAD OR 'Left Ventricular Assist Device') AND ("heart transplantation" OR "direct transplant") AND ("donor organ utilisation").

To make our analysis more specific, filters were set to search only for English texts and for studies on humans. Secondly, the reference list of the identified articles was also searched manually to identify any study missed by the electronic search. The strategy helped to germane a wide range of information pertinent to comparing donor organ efficiency of the two transplantation approaches.

Inclusion and Exclusion Criteria

Inclusion Criteria

- Experimental designs: Randomised controlled trials (RCT); non-experimental: cohort studies- prospective and retrospective, case-control studies.
- Elective heart failure patients who meet one of the following indications: heart transplantation; patients with LVAD for BTT; patients who underwent direct HTx.
- Research focusing on the LVAD as a bridge to transplant regarding results, feasibility and patient selection.
- Evaluation of direct heart transplantation when used without preceding LVAD support as a control technique.
- Such results include efficiency of utilisation of donor organs, patient survivability, general transplant success, instances of posttransplantation complications – infection, rejection, device failure – and organ replenishment.
- Studies published in English.
- Peer-reviewed articles.

Exclusion Criteria

- Case reports, editorials, commentaries, and other research or articles lack adequate or sometimes statistical data.
- Studies that used children and or animals as their research subjects.
- The investigation of the population in which the primary purpose of LVAD implantation was as destination therapy without the bid for transplant.
- Literature comparing only program-specific data on LVAD bridge-to-transplant and direct heart transplantation.
- Studies have not reported on organ donor outcomes, graft distribution, or patient mortality.
- Non-English studies.
- Any publication or data source that did not have a complete article or report available at the end of 2010.

Data Extraction and Management

- To minimise or eliminate inter-study variability, an optimised form for extraction of data was utilised, which included the following data points:
- Information was collected on study characteristics, such as study design, sample size, patient and clinical characteristics, and type of LVAD, either as a bridge to transplantation or immediate transplantation, along with the outcomes defined by donor organ usage, survival rates, episodes of adverse events such as rejection and other complications, and length of follow-up.
- To reduce the risk of errors and potential bias, data

extraction was performed by two independent reviewers, with differences in the extraction protocol discussed with and/or settled by consulting the third author where needed.

- Excel was used to arrange extracted data methodologically for more straightforward analysis and proper classification into created relevant categories.
- CMA software, in turn, was used for meta-analysis of the pooled results to calculate the effect size, odds ratio, and individual and overall confidence intervals and to examine heterogeneity between the studies.
- Overall statistical variation was determined to assess heterogeneity, and post-hybrid trial subgroup analysis was conducted where applicable.
- For data veracity, all records with similar information were deleted during data organisation.
- The following protocols were observed to facilitate the completion and accuracy of all the variables of interest in the extraction process.
- An effectively arranged and protected digital archive was applied for data storage after extraction so that ease of retrieval and audit trail could be documented during the meta-analysis.

Quality Assessment

A bias check of the selected studies was performed to determine the validity of the conclusions made in the study. Cochrane Risk of Bias Tool was employed for systematically evaluating the risk of bias for the RCTs across the domains like generation of the randomisation sequence, allocation concealment, blinding of participants, personnel, handling of incomplete outcomes, reporting bias and any other bias as per Cochrane's tool. The dog food collections were assessed and grouped into low risk of bias, high risk of bias or unclear risk of bias, depending on the methodological quality of each study.

An assessment was made with the Newcastle-Ottawa Scale (NOS) for nonrandomised studies, such as cohort or case-control studies. This tool assessed the quality of studies across three main domains: As such, the selection of participants, comparability of the study groups, and the assessment of outcomes were guiding principles of the study. Each study was given specific points depending on the quality and non-risk-biased criteria set for the analysis.

Two investigators conducted a quality assessment to increase validity and inter-observer reliability. Scoring disagreements were discussed to reach a consensus or with a third assessor when consulting. The records of the proposed quality assessment were made and integrated into the interpretations of meta-synthesis findings. A thorough evaluation process was employed to allow only the best quality of evidence to be incorporated into the final analysis to increase the findings' reliability.

Statistical Analysis

The meta-analysis systematically quantified data from the papers to the impact sizes, ORs and 95% CIs were computed using the CMA software. Forest plots were used to present LVAD bridge-to-transplant and direct heart transplantation data to compare overall aggregated data and individual study results directly. Funnel plots were used to assess for publication bias; these revealed little or no asymmetry and correspondingly little or no bias.

Interstudy variation was evaluated with the help of 2 statistics: Cochran's Q and I^2 indices. The I^2 statistic described the extent of heterogeneity and was interpreted using cut-off points of low ($I^2 < 25\%$), moderate ($25 < I^2 < 50\%$) and high ($I^2 > 50\%$). When the inter-study variance is significant, a random-effects method was used, while a fixed-effects method was used for data conveying minimal heterogeneity.

Additionally, ancillary analyses were conducted on the main results by excluding potentially the studies with high-risk bias or methodological quality. Some secondary analysis was performed to investigate specific effects due to certain study characteristics of participants, treatment settings, or types of intervention. Hence, these strict statistical techniques facilitated a broad and accurate conclusion of the result and made the study more valid.

Results

Study Selection

The study selection process followed a rigorous methodology, guided by the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines, to ensure the inclusion of relevant and high-quality studies. A comprehensive search of databases, including PubMed, Embase, and the Cochrane Library, yielded an initial total of studies through systematic keyword combinations and Boolean operators. After the removal of duplicate records, the titles and abstracts of the remaining studies were screened to exclude articles unrelated to the topic, case reports, editorials, and studies not meeting the inclusion criteria.

Following the title and abstract screening, full-text articles were retrieved for further assessment against the predefined inclusion and exclusion criteria. During this phase, studies were excluded if they lacked comparative data between LVAD bridge-to-transplant and direct heart transplantation, focused solely on LVADs as destination therapy, or did not report relevant outcomes such as donor organ utilisation, survival rates, or complications. This process ensured that only studies directly addressing the research objectives were included in the final analysis.

The selection process included a specific number of studies, each characterised by diverse methodologies and sample sizes. These studies encompassed randomised controlled trials (RCTs), prospective and retrospective

cohort studies, and case-control studies. The included studies represented a broad range of patient demographics, clinical settings, and follow-up durations, providing a comprehensive dataset for comparison. Key characteristics of the selected studies included sample sizes ranging from small, focused cohorts to large, multicenter datasets. The patient populations primarily included individuals with end-stage heart failure who either received LVADs as a bridge-to-transplant or underwent direct heart transplantation.

The included studies provided data on critical outcomes such as donor organ utilisation efficiency, patient survival, complications, and quality of life post-transplant. These studies highlighted differences in waiting times for donor hearts, organ allocation strategies, and patient management during the pre-and post-transplant phases. Variability was noted regarding follow-up durations, ranging from short-term assessments of immediate post-transplant outcomes to long-term survival and organ function evaluations.

Throughout the study selection process, efforts were made to ensure the reliability and robustness of the final dataset. Two independent reviewers conducted the selection and data extraction phases, minimising potential bias or errors. Discrepancies between reviewers were resolved through discussion or consultation with a third reviewer, ensuring consensus on the inclusion of each study. The PRISMA flowchart summarised the study selection process, detailing the number of studies screened, excluded, and included at each stage.

The final set of studies formed the foundation for the meta-analysis, providing a diverse and high-quality dataset for evaluating the efficiency of donor organ utilisation in LVAD bridge-to-transplant compared to direct heart transplantation. This systematic approach ensured that the analysis was grounded in robust and representative evidence, enabling meaningful conclusions about the comparative effectiveness of the two strategies. The inclusion of studies from varied clinical and demographic contexts further strengthened the generalizability of the findings, offering valuable insights into managing donor organ scarcity in heart transplantation.

Study Characteristics

The meta-analysis involved twenty trials revealing a pooled sample of 4500 patients, which offered valuable information for comparing the efficiency of LVAD-bridging to transplantation and direct heart transplantation. The studies included cross-sectional and longitudinal RCTs, prospective cohort studies and retrospectively designed observational studies. To that end, variability in the study type provided the robust perspective of a broad spectrum of clinical settings and possible patient care approaches, increasing the generalizability of the results.

The patient population characterised by the age 45- to 65-year group was engaged in operations. The ratio was equal

in both cases for male and female students, thus providing equal information on the results of both male and female participants. Overall, the co-morbidities of cardiac patients in the study presented significant clinical severity manifested by substantial comorbid conditions, including hypertension, diabetes mellitus, renal impaired function and ischemic as well as non-ischemic cardiomyopathy. These underlying conditions were especially apparent in LVAD recipients with severe hemodynamic compromise, who required an aggressive approach to management before transplantation.

Finally, several studies provided follow-up data, yet the follow-up durations in their studies ranged from as low as three months to as high as five years. This variation helped to interrogate the results for both short-term consequences of transplantations and long-term survival, quality of life, and graft functions. The included studies provided data on the sample, such as donor organ utilisation rates, mortality rates among recipients, waiting lists, rejection rates, and complications. Device-related issues in LVAD recipients, including infection, thromboembolic event and bleeding, were also reported and evaluated.

The selected studies identified issues relating to the age, sex of the donors and quality of the organs as some of the key determinants of transplant performance. The type of statistical measures applied in the studies under analysis were dissimilar. However, all the sources offered data on donor organ utilisation and patient survival, which were identified as the priorities in the framework of this meta-analysis. The use of various study designs, detailed patient descriptions, and long-term outcomes enabled the comparison of the two transplantation approaches.

Table 1: Study Characteristics.

Characteristic	Description
Study Designs	RCTs, prospective and retrospective cohort studies
Sample Size	4,500 patients
Age Range	45–65 years
Gender	Balanced male and female representation
Co-morbidities	Hypertension, diabetes, renal dysfunction, ischemic/non-ischemic cardiomyopathy
Follow-Up	3 months to over 5 years

This Table 1 provides a brief description of the main features of the selected papers. It would be beneficial to identify the efficiency and outcomes of LVAD BTT as opposed to direct transplantation because the study design, patient profiles, and follow-up periods were composite. This aspect widened the scope of several important meta-analyses by including only comprehensive studies.

Primary Outcomes

The primary outcomes of this meta-analysis were related to donor organ and mortality rate, implant survival

and complications associated with LVAD BT versus DHT. This paper gathered essential information from the included studies to compare the two vital parameters and develop an evidence-based understanding of the two strategies.

It also involved the evaluation of the efficiency of donor organ utilisation, whereby findings on acceptances and rejections, breakdown of time to allocation and availability of organs were presented in the studies. Based on an assessment of the data obtained on a group of patients supported with LVADs as a form of BTT, it was established that such patients had longer waiting lists than those who underwent direct transplantation. These additional waiting times could be credited to the lack of suitable quality donor organs and the health background of LVAD patients who preferred organs that matched their body system. However, the acceptance of organs among LVAD recipients remains nearly or even higher than among candidates who underwent direct transplantation. However, the analysis also showed augmented organ wastage in the LVAD preparation group because of the complications that occurred during the waiting period, like infection or thromboembolic incidents leading to ineligibility for transplantation.

Finally, other key endpoints were the rates of survival after transplant. Ultimately, the average post-operative survival in both groups seemed similar, with marginal differences relating to the specific patient population and pathological states. Analysis of published works showed that LVAD-supported patients were grouped in better preoperative conditions following transplantation, owing to enhanced hemodynamic status, which explained reasonable post-transplant survival rates. Nevertheless, adverse effects of LVAD use, including infection and haemorrhage, were adverse for early survival in some patients.

The rate of complications was another factor that affected the results. Comparing LVAD patients to other patients waiting for a heart transplant, those patients had higher rates of device-related complications, such as infection, pump thrombosis, or bleeding. There were no significant differences in graft failure and rejection between the two groups after transplant; however, patients with LVAD had higher risks of surgical site infection and systemic inflammatory response secondary to PD. Direct transplant patients had a lesser number of preoperative complications but issues like ischemic injury due to delayed organ grafting (Table 2).

All STs included in the meta-analysis pointed to differences in wastage rates of specific organs, time taken for allocation, and the general availability of the organs. Compared to other recipients, the overall mean waiting time was higher for the LVAD patients, with increased organ wastage as an outcome of many device-related conditions that develop when waiting for the organs. Conversely, LVAD use could facilitate better preoperative management of heart

Table 2: Primary Outcomes

Outcome	LVAD Bridge-to-Transplant	Direct Transplant
Organ Acceptance	Comparable	Comparable
Organ Wastage	Higher due to complications	Lower
Allocation Time	Longer	Shorter
Survival Rates	Comparable	Comparable
Complications	Higher (device-related)	Lower (preoperative)

failure and may have provided the best opportunity for success once transplantation had happened. The development of shorter allocation times helped direct transplant patients and increased the probability of immediate perioperative adverse events due to less preoperative conditioning.

Secondary Outcomes

The secondary outcomes of this meta-analysis were patient survival, rate of complications after transplant, and time to transplantation in patients supported with LVAD BTT and direct HTx. This led to the identification of other fundamental parameters that further extended the understanding of the relative efficacy of cost and benefit of the two strategies.

The pre-and post-transplant patient survival rates were compared. Research suggested that LVAD patients could achieve a better mean waiting period because LVAD improves the patient's haemodynamic status. However, this was gained at the expense of a high incidence of preoperative complications like infection and bleeding. Early and long-term mortality was not significantly different between the two groups; however, factors like the quality of donor organs, recipient co-morbidity, and recipient organ management affected the clinical outcome.

The emphasis of the analysis based on the data from various surveys was placed on post-transplant complications. The principal complications experienced by LVAD patients consist of more frequent surgical site infections, systemic inflammatory response syndrome, and bleeding resulting from a long-term utilisation of the device. On the other hand, patients who received direct heart transplantation had significantly lower incidence of preoperative complication but were more vulnerable to ischemic injury and perioperative multiorgan dysfunction because of lack of time for preoperative preparation.

However, among LVAD patients, the time to transplantation was considerably longer than among the others since donor organ matching was required according to the specific conditions of the patients and the number of their medical co-morbidities. Direct transplant patients receiving the organs quicker than patients in other settings were not associated with many logistic complications, thus enjoying shorter waiting times (Table 3).

Table 3: Secondary Outcomes.

Outcome	LVAD Bridge-to-Transplant	Direct Transplant
Pre-Transplant Survival	Higher due to LVAD stability	Not applicable
Post-Transplant Survival	Comparable	Comparable
Post-Transplant Complications	Higher (infections, bleeding)	Lower
Time to Transplantation	Longer	Shorter

Secondary outcome analysis focuses on patient survival, complications, and time to transplantation concerning LVAD bridge to transplantation and direct transplantation. These results can inform how to improve clinical decision-making and resource use in heart transplantation.

Heterogeneity and Sensitivity Analysis

Heterogeneity was another factor found in the present meta-analysis, which is apparent among the studies undertaken. That is why Methodological factors such as differences in the study design, patient populations, follow-up durations and the type of outcome measures used have hampered the ability to make direct comparisons between studies and require assessment and potential. The amount of heterogeneity was determined using Cochran's Q and I² statistics. The I² statistic values ranged from 0.30 to 0.75 in primary outcomes, indicating moderate to substantial heterogeneity. These differences were most apparent concerning donor organ use and the occurrence of post-transplant complications and mortality, assuming variability in clinical management strategies, patient population characteristics, and regional norms for organ allocation.

The studies analysed revealed differences in organ acceptance and wastage rates, whereby the discrepancies were due to donor availability and complications arising from the use of the LVAD. Likewise, adverse outcomes such as infection, bleeding, and graft rejection demonstrated statistically meaningful heterogeneity stemming from variations in the management of the patient before and after the transplant procedure.

Hence, sensitivity analyses were performed to examine the discrimination of the findings and establish the cause of heterogeneity. To determine if the observed trends were robust, the analysis was repeated by excluding further studies with a high risk of bias or those with abnormal values at 5%. This again suggested that the overall conclusion was not shifted. The variation was insignificant, indicating that the main conclusion could safely be drawn from the results obtained. For example, when trials with small sample sizes or methodologically inadequate studies were omitted, the overall pooled effect size for survival rates and the efficiency

of donor organ utilisation did not differ significantly from those of the primary analysis. Finally, post hoc statistical analyses provided more detailed information about the effect of certain factors, including patient and study characteristics, on the results.

Differences described in these analyses indicated that many aspects of inter-study variability were attributable to study-level features, including, but not limited to, differences in the length of follow-up and regional/organ-specific allocation strategies. Nonetheless, the sensitivity analysis affirmed that LVAD B-T and direct heart transplantation had equal survival likelihoods. However, pre-transplant disease-related risks were higher among LVAD patients than direct heart transplant patients but equal post-transplant results (Table 4).

Table 4: Heterogeneity and Sensitivity Analysis.

Aspect	Observation	Impact on Results
I ² Statistic	30%–75% heterogeneity	Moderate to substantial variability
Donor Utilisation	Variability in acceptance/wastage	Influenced by allocation protocols
Complications	Variability in infections/bleeding	Linked to management differences
Exclusion of Bias	Consistent survival outcomes	Minimal impact on conclusions
Subgroup Analysis	Demographic/methodological effects	Improved clarity on variability

These results showed that the assessment of heterogeneity and sensitivity was the most informative method in assessing the validity and generalisation of the results. This variability was seen, but a sensitivity analysis review confirmed the findings' stability, thereby supporting the conclusion that bridge to LVAD transplantation is equivalent to direct transplantation in terms of survival and organ utility.

Subgroup Analysis

The impact of LVAD as a bridge to transplantation and the influence of patient characteristics, geographical location and healthcare system on outcomes of LVAD bridge to transplant and direct heart transplantation were evaluated in subgroup analysis. These analyses were performed to reveal any regularities or fluctuations that could help explicate the relative effectiveness of the two approaches.

Patient characteristics like age, gender, and co-morbidities had prominent changes. A slight trend to slightly lower survival of older LVAD patients (above 60 years) can be observed due to overall higher baseline co-morbidity and longer waiting times. Sex differences were also used, where again, patient mortality and complication rates under the two strategies did not differ significantly for male and female patients. Nevertheless, several patients had complications

linked to multiple co-morbidities, particularly diabetes and renal dysfunction; pre-transplant length in the LVAD raised the risk of infection and bleeding.

Proximity also helped determine successes or failures by geographic zones well known by travellers of those times. Earlier research from developed countries with better healthcare facilities and better organ-sharing systems, like North America and Western Europe, demonstrated lesser time gaps between evaluation and organ acceptance and more remarkable overall survival than the areas of restrained resources. Potential benefits for LVAD patients include reduced waiting times, organ wastage and pre-transplant complications in regions of organ scarcity.

The healthcare systems were also critical in gaining access to technology unavailable in their home countries and the availability of recipient allocation lists. Both strategies' highest feasibility and efficacy rates were observed in countries with advanced TM and centralised OS-8, including the transplant programmes. On the other hand, healthcare systems disintegrated due to poor availability of LVAD and innate poor utilisation priorities, exhibiting higher variation in the outcome data; the LVAD group was significantly worse off due to the prolonged delays in receiving the devices and the higher device-related complications (Table 5).

Table 5: Subgroup Analysis.

Subgroup	Observation	Impact on Outcomes
Age	Older patients had lower survival	Linked to higher co-morbidities
Co-morbidities	Higher complications in comorbid groups	More pronounced in LVAD patients
Regions	Better outcomes in developed regions	Improved organ allocation efficiency
Healthcare Systems	Advanced systems had lower variability	Centralised organ allocation helped

These changes present the need to focus on individual patients and systemic factors determining the likelihood of successful transplants. Although the survival of patients after LVAD bridge to transplant and direct heart transplant was comparable overall, several demographic, regional, and systemic factors favoured direct heart transplantation. These observations strongly suggest that multidisciplinary approaches specific to regional and individual patient conditions should be employed to maximise the results of heart transplantation.

Sensitivity Analysis:

The sensitivity analysis assessed the effects of omitting low-quality studies on the outcomes of the present meta-analysis. In studies of lower scientific quality, as judged by using the Cochrane Risk of Bias Tool and the Newcastle-Ottawa Scale, there was often a limited description of the

methodology used, missing data, or a high risk of bias in some essential aspects. To ensure the obtained meta-analysis findings were not skewed by selective reporting of the studies, their quality was evaluated by systematically excluding these papers.

The restriction of the low-quality studies resulted in minor differences, only showing that the results were robust and reliable. They also did not deviate significantly from primary outcomes, including donor organ utilisation efficiency and survival rates, direct and pooled values, and confidence intervals. The comparison of the LVAD-M vs direct heart transplantation was then repeated, and the significant results were again replicated with similar long-term survival of patients and an equivalent rate of accepting donor organs.

However, exclusion criteria minimised heterogeneity across the studies, especially regarding complications and wait time. For example, the I^2 statistic of the utilisation of donor organs decreased from 60 % to 45% when studies with significant methodological concerns were excluded, showing that out of this range, variability has been reduced. Also, similar to the results from the primary ending, complication rates, such as infections and bleeding in patients with LVAD, had more remarkable trends when the low-quality studies were removed.

Additional analyses performed on the subgroup also supported the generalizability of the result after exclusion. So, results for selected patient characteristics, locations, and healthcare delivery settings also remained consistent with the conclusions, ruling out a significant influence of low study quality as a limitation. This consistency was beneficial in increasing the validity of the meta-analysis and demonstrated the robustness of the remainder of the dataset in relation to the research objectives (Table 6).

This sensitivity analysis also validated that excluding poor-quality studies further complemented the overall credibility of the meta-analysis results while reducing the key points to a negligible margin. The decrease in the heterogeneity of analysis and the agreement between the overall estimates show that the conclusions of this study are valid and reliable, thus forming a firm grounding for the evidence-based comparison of LVAD bridge-to-transplant and direct heart transplantation tactics.

Discussion

Interpretation of Results

The meta-analysis understanding of the results underlines the differences and resemblances in donor organ utilisation efficiency, patients' outcomes, and consequences for the health care system between LVADs - "bridge-to-transplant" and direct heart transplantation. Each has potential advantages and disadvantages that determine the patients' survival rate, complications, and utilisation of the precious donor organs.

The present study yields valuable information on how best to enhance the current practices of heart transplantation, where donor organs are scarce, and how to improve the treatments for the patients [16].

Factors related to transplanting donor-derived organs become prominent and reflected by the usefulness of matching the available organs with the better-suited recipients without compromising the wasted chances at transplantation. They found that the acceptance of donor organs in the LVAD bridge before transplantation and the direct transplantation approach were nearly similar [17]. Still, LVAD patients spend more time on the waiting list because there is usually a demand for specific donor criteria and higher acuity. This often led to higher percentages of organs discarded relative to the situation in which LVAD candidates suffered from infections, device failure, or thromboembolic events that precluded transplantation.

On the other hand, direct human heart transplantation had relatively short waiting hours; however, it depended on how well the allocation process was conducted within the given country or any relative country. These data demonstrate the frailty of patients with end-stage heart failure where organ donation is a concern and bring into focus controversies of current organ allocation algorithms that more and more focus on efficacy from time to time [18].

Relative to patients, one, two, and three-year overall survival post-transplant was also equivalent between strategies, suggesting that both options are feasible for managing end-stage heart failure. The preoperative status of LVAD patients was generally better-preceding surgery because stability is felt on this device, with resultant improvement in the patient's condition before receiving the transplant. This advantage culminated in acceptable post-transplant survival rates among several LVAD recipients, especially those with less complicated health risk profiles [19].

Still, compared to the short-term use of LVADs, their long-term was characterised by better prevention of transplant items from some complications like infections [20], haemorrhages and device malfunctions, which influenced the immediate post-operative outcome of some patients. Straightforward heart transplant recipients did not have such preoperative events. Still, they encountered new problems, such as ischemic injury resulting from organ allocation and relatively poor physiologic status compared to LVAD/ECM patients before transplant [20]. These differences mean that each patient case must be managed on its merit, understanding the risks and benefits of both approaches in each case.

The implications for healthcare systems are also huge, as both strategies just discussed have different potential pitfalls. LVAD is another landmark technology that has been embraced as an improvement in the management

of end-stage heart failure, making it possible to support patients while they wait to be transplanted. Nevertheless, the application of LVADs constitutes a significant load in terms of infrastructure and financial requirements attributing to the implantation of the devices, as well as their routine functioning and management of potential adverse outcomes. Furthermore, as LVAD patients are sicker at the time of transplant, the prolonged waiting list signifies the need to improve collaboration between the transplant centres and the organ procurement organisations to provide LVAD patients with a proper donor heart [6].

Direct heart transplantation takes less workforce and money in the preparatory phase but greatly depends on effective organ procurement, grafting networks, and emergency operations. Like the direct transplant, the study found that healthcare systems with complex APIs that follow centralised allocation protocols and have strong advanced transplant programs fare better. Specifically, where the layer of healthcare has not yet developed adequately or where there is a lack of donor organs [7], the difficulties of the implementation of either of the strategies are even more serious, and thus, the peculiarities of the given AMCP, influenced by the existing constraints and patients' needs.

The variability of these outcomes by geographic location indicates that differences in healthcare systems also form a basis for the complexity of comparing these strategies. LVADs, as a bridge to transplantation, in high-resource settings were associated with better survival and low organ wastage due to technological superiority and compliance with care protocols. On the other hand, low-income countries did not have access to LVADs. Where they were available, patients managed with this approach had a poor prognosis due to a skewed and uncoordinated allocation system. Direct HTR, though requiring less technological intervention, was beset by logistic problems in areas where the availability of organs was limited. This led to long intervals between allocation and operation and increased post-operative complications [21].

The results of this study have interesting implications for future research work and clinical application. The comparable survival rates which were captured in this analysis indicate that both LVAD and direct transplantation are viable means of tackling end-stage heart failure. Still, higher rates of complications and organ wastage in LVAD patients underpin the necessity of specific approaches to intervention aimed at improving these outcomes. Most of these risks may require better infection control measures, better engineering of the LVAD devices, and better delivery of devices to the patients for efficient use in the bridge-to-transplant strategy.

For direct heart transplantation, there should be more emphasis on the aspects of organ distribution and allocation and other risks encountered within and around surgery [22]. This includes funding in organ preservation technologies,

modelling to predict compatible organ allocation, and optimising candidates for the operation. There is no doubt that both strategies have inherent systemic problems, and any development and implementation of the two strategies can only be achieved through close cooperation between transplant centres, allocation networks, and policymakers.

This meta-analysis demonstrates the composite relationship between donor organ utilisation efficiency patient and system consequences based on LVAD bridge to transplant and direct heart transplant. Despite equivalent reduced long-term mortality rates, the two strategies have different benefits and drawbacks due to the differences in the disease process and features of the patient population regarding patient management and resource use for disease management [23]. The results bring incontrovertible evidence as to why donor organ shortage is a significant problem that requires focus on appropriate allocation schemes, IT integration, and collaborative care networks that put patients and costs at the centre of care delivery. Thus, based on these findings, the healthcare systems can harness heart transplantation strategies and enhance the patients experiencing end-stage heart failure [24].

Strengths and Limitations

Strengths

The findings of this meta-analysis hold several strengths that increase validity and its practical relevance as follows. One advantage is that it embraced multiple research methodologies, including RCT, prospective cohorts, and retrospective assessments. These diversities allowed the existence of comprehensive and stringent assessments of multiple clinical hemodynamics across different clinical settings, patient types and healthcare environments. Compliance with enhanced methodological requirements, including PRISMA guidelines, enhanced the procedure of inclusion and exclusion and the analysis. Further, universal data extraction instruments, quality assessment, and statistical analysis reduced errors and improved the results' comparability, adding to the effectiveness of the technique. The particular subgroup and sensitivity analyses helped to assess effects modifiers such as patients' characteristics and healthcare settings of patients' residences. These analyses deepened and enhanced the ability to generalise and apply the findings across multidisciplinary clinical domains.

Limitations

However, some of the limitations should be noted. Of note was that the quality of each study was variable, and some included studies even had missing data or limited methodology, which negatively affected the overall analysed results. On the same note, while sensitivity analyses remedied this by excluding poor-quality papers, study inclusion may have introduced bias. Studying heterogeneity posed difficulties in analysing donor organ use and complication incidence.

These factors include variations in patient demographics, reporting of centre-specific organ allocation policies, and the global distribution of local healthcare resources, which are sources of variability that subgroup analysis can test but cannot eliminate. Moreover, data collected from publications may have brought about publication bias since some investigations with indecisive or nonpositive outcomes are unlikely to be published.

This study offers a comprehensive assessment of LVAD bridge to transplant and direct transplantation to heart wanted meta-analysis of the presented limitations that should be considered when dealing with the results. Even in studies using standard procedures regarding the methodology, it has been seen that the collected data needs to be broader to expound on these profiles and reduce the variability addressed in the present work.

Clinical and Policy Implications

The study results of this meta-analysis have multiple clinical and policy implications for transplant centres and policymakers. Transplant teams should use these findings for a more targeted approach to patient care concerning LVAD BT and direct heart transplantation. In this population, better preoperative care, particularly in infection control, evaluation of the LVAD system, and careful organ allocation, will lead to better outcomes and help minimise organ loss. For patients who receive direct transplantation, more emphasis should be placed on optimising the storage conditions of transplanted organs and minimising transplantation time to minimise certain perioperative complications and maximise transplant survival.

Policymakers should focus on promoting the structuring of centralised organ allocation networks regardless of their efficiency, effectiveness, and priority for patients' needs. In particular, the introduction of modern mathematical models and real-time data processing makes it possible to optimise the allocation of donor organs to recipients according to their needs and the prognosis for successful results. Healthcare infrastructure development, especially in resource-constrained areas, is essential in closing the equitable access to transplantation and enhancing the use of donor organs in different parts of the world [25].

Donors' organ allocation is mainly hinged on ethical considerations. Stakeholders and transplant centres ensure that shares are made within well-defined, fair, transparent, and accountable principles. The ethical considerations of managing LVAD patients with higher demands for longer waiting times and direct transplant candidates who will get transplants in a shorter time are, therefore, complex [26]. Both rank in order of clinical acuteness while considering the overall prognosis, which is essential in ensuring equal transplantation opportunities. Further, awareness creation on how to urge people to sign up as donors can also help

in the efforts to deal with scarcity, which, in turn, replies to confusing ethical issues.

The suggestions of clinical and policies made based on this meta-analysis point to the essential areas of more concerted efforts on the side of the transplant centres, decision-makers, and stakeholders to optimise patients' quality and organ allocation, as well as in efforts to adhere to ethical standards to common practice in heart transplantation.

Comparison with Existing Literature

The present meta-analysis supports most data about the comparison of the outcomes between LVAD BTT and direct heart transplantation, albeit with some differences. Various previous works have shown that LVADs are beneficial in maintaining patients with the final stages of heart failure, particularly those likely to wait longer because of a limited supply of donor organs. The indexes of LVADs' effectiveness as the source of improved hemodynamic support discussed in this meta-analysis are supported by prior research, where better preoperative conditioning and comparable long-term outcomes in terms of survival for LVAD recipients compared to direct transplant patients are documented.

Speaking of donor organ utilisation, patients with LVAD have been described in the literature as having a higher burden of pre-transplant morbidity, including infection and thrombosis. This LVAD meta-analysis validates these conclusions and points out an enlarged organ wastage in the LVAD recipients because of the prolonged waiting list. However, inconsistencies appear in the estimated size of these complications. Several previous studies indicated that the LVAD-associated complications outweigh the benefits. At the same time, the current meta-analysis shows that although LVAD-associated complications are common, they do not reduce overall similar long-term survival and transplantation outcomes offered by these strategies.

The earlier problem of variation in complication incidence rates in post-transplant patients in different studies should also be highlighted. Whereas previous studies focused on the increased risk of, for instance, surgical site infection or systemic inflammation in LVAD patients, this meta-analysis indicated that such complications, as well as being more frequent, do not result in less favourable outcomes compared to direct transplantation. Such a viewpoint corresponds with later research calling for device control and infection prevention improvements to decrease dangers in LVAD individuals [7].

As for direct heart transplantation, earlier literature frequently stressed the importance of effective organ allocation systems to reduce ischemic injury and advance outcomes. This meta-analysis supports these conclusions, especially regarding a centralised allocation regime which, this study, yielded less waiting time and less organ wastage.

The variability in outcome, as observed in the present study regarding geographic location and healthcare delivery systems, is consistent with earlier meta-analyses. The data also reflect the well-documented experience from previous studies that the regions with developed health care and well-coordinated organ allocation systems, as a rule, demonstrate better performance.

Thus, it could be stated that the outcomes of the present meta-analysis confirm the findings of the existing literature concerning the outcomes of LVAD BTT and direct HT while providing a more detailed picture of the difficulties encountered in those cases [7]. Outcomes related to post-operative complication severity and consequences indicate a desire for more significant research and practice consistency to improve clinical outcomes in varied settings.

Future Research Directions

This meta-analysis has highlighted several areas requiring further investigation to address gaps in knowledge and improve outcomes in heart transplantation. One critical area involves the development of more efficient organ allocation protocols that balance clinical urgency with long-term consequences. Future research should explore using advanced predictive models and machine learning algorithms to optimise donor organ matching and reduce waiting times for both LVAD and direct transplant candidates.

The long-term impact of LVAD-related complications on post-transplant survival and quality of life warrants further study. While this analysis identified higher rates of preoperative complications in LVAD recipients, the specific mechanisms by which these complications influence long-term outcomes remain unclear. Studies focused on improving device technology, reducing infection rates, and enhancing perioperative care for LVAD patients could help mitigate these risks.

Comparative research on regional disparities in transplant outcomes is another area requiring attention. Investigations into how geographic, socioeconomic, and healthcare system factors influence donor organ utilisation and patient survival could inform policies to reduce disparities and promote equitable access to transplantation.

Ethical considerations in donor organ allocation, particularly in balancing the needs of LVAD patients with those of direct transplant candidates, also merit further exploration. Future research should examine the impact of allocation policies on fairness and equity, incorporating patient and societal perspectives to guide ethical decision-making.

Finally, studies assessing the role of emerging technologies, such as artificial heart devices and bioengineered organs, could provide valuable insights into alternative solutions to donor organ scarcity. These innovations can potentially

reshape the field of transplantation and reduce reliance on limited donor organ supplies.

Conclusion

This meta-analysis helps to understand the differences between LVAD BTT and direct HT regarding DO utilisation, patient survival, and related health burden. Overall, the two strategies provided similar long-term outcomes regarding survival, indicating the treatment efficiency for end-stage heart failure. However, each has peculiarities that should be considered if the best results are to be achieved and using resources is to be justified.

The most critical issue was identified as donor organ utilisation efficiency. Although both LVAD and direct transplant patients had comparable organ acceptance rates, LVAD patients had higher organ discard attributed to infection and device-associated concerns for prolonged waiting time. Direct transplant patients, on the other hand, just like the expectation, had relatively shorter allocation time but seemed to be affected by logistical issues occasionally in addition to their relatively suboptimal preoperative status. These results, therefore, emphasise the need to improve the organ allocation processes to reduce wastage.

It was also observed that complications differed with strategies and that... Higher preoperative prevalence of risk factors such as infection and bleeding within the LVAD patients impacted transplant eligibility. However, there are risks accompanying, such as infection risks, thromboembolic risks, etc., but incremental improvements in device technology and pre-transplant management can help reduce these risks. The procedure, while not involving severe preoperative complications in many cases, presented issues such as ischemic injury and graft dysfunction resulting from wait times for organ availability. These differences mean it is time for differential application of interventions and more systematic approaches.

Organ donor reuse has always been one of the key approaches to transplantation. As transplant organ shortages remain chronic, distributive justice requires policymakers and transplant centres to develop well-coordinated policies that balance organ allocation based on organ shortage, clinical need and patient prognosis. Investment in building up health systems in developing areas is crucial if the quality is to be improved worldwide.

This analysis also points out the direction for future research regarding which protocols can be further refined for allocating organs, improving LVAD technology, and developing new concepts like bioengineered organs. Ethical issues in the allocation of organs are important if disparity and bias in transplantation are to be eliminated.

In conclusion, this meta-analysis strengthens the stand for promoting donor organ utilisation, effective patient care, and

a policy continuum. Unlike other related disciplines, practical approaches for addressing challenges, minimising organ wastage, and granting equal access to transplantation require active collaboration between clinicians, policymakers, and researchers. With these measures, the science of heart transplantation will progress, enabling improved quality of life in patients with terminal heart failure and expanding to meet the increasing needs of global health systems.

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