Medical Policy

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Title: Total Artificial Hearts and Ventricular Assist Devices

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Populations	Interventions	Comparators	Outcomes
Individuals: • With end-stage heart failure	Interventions of interest are: • Ventricular assist device as a bridge to heart transplant	Comparators of interest are: • Optimal medical therapy	Relevant outcomes include: • Overall survival • Symptoms • Functional outcomes • Quality of life • Treatment-related mortality • Treatment-related morbidity
Individuals: • With end-stage heart failure	Interventions of interest are:	Comparators of interest are: • Optimal medical therapy	Relevant outcomes include: • Overall survival • Symptoms • Functional outcomes

Populations	Interventions	Comparators	Outcomes
	• Ventricular assist device as destination therapy		• Quality of life • Treatment-related mortality • Treatment-related morbidity
Individuals: • With end-stage heart failure	Interventions of interest are: • Total artificial heart as a bridge to transplant	Comparators of interest are: • Optimal medical therapy	Relevant outcomes include: • Overall survival • Symptoms • Functional outcomes • Quality of life • Treatment-related mortality • Treatment-related morbidity
Individuals: • With end-stage heart failure	Interventions of interest are: • Total artificial heart as destination therapy	Comparators of interest are: • Optimal medical therapy	Relevant outcomes include: • Overall survival • Symptoms • Functional outcomes • Quality of life • Treatment-related mortality • Treatment-related morbidity
Individuals: • With cardiogenic shock	Interventions of interest are: • Percutaneous ventricular assist device	Comparators of interest are: • Intra-aortic balloon pump	Relevant outcomes include: • Overall survival • Symptoms • Morbid events • Functional outcomes • Quality of life • Treatment-related mortality • Treatment-related morbidity
Individuals: • Who undergo high-risk cardiac procedures	Interventions of interest are: • Percutaneous ventricular assist device	Comparators of interest are: • Intra-aortic balloon pump	Relevant outcomes include: • Overall survival • Symptoms • Morbid events • Functional outcomes • Quality of life • Treatment-related mortality • Treatment-related morbidity
Individuals: • With cardiogenic shock refractory to intra-aortic balloon pump	Interventions of interest are: • Percutaneous ventricular assist device	Comparators of interest are: • Optimal medical therapy • Other mechanical circulatory support	Relevant outcomes include: • Overall survival • Symptoms • Change in disease status • Functional outcomes • Quality of life • Treatment-related mortality • Treatment-related morbidity

DESCRIPTION

A ventricular assist device (VAD) is mechanical support attached to the native heart and vessels to augment cardiac output. The total artificial heart (TAH) replaces the native ventricles and is attached to the pulmonary artery and aorta; the native heart is typically removed. Both the VAD and TAH may be used as a bridge to heart transplantation or as destination therapy in those not candidates for transplantation. The VAD has also been used as a bridge to recovery in patients with reversible conditions affecting cardiac output.

OBJECTIVE

The objective of this evidence review is to determine whether ventricular assist devices and total artificial hearts improve the net health outcome in individuals with end-stage heart failure or cardiogenic shock.

BACKGROUND

Heart Failure

Heart failure may be the consequence of a number of etiologies, including ischemic heart disease, cardiomyopathy, congenital heart defects, or rejection of a heart transplant. The reduction of cardiac output is considered to be severe when systemic circulation cannot meet the body's needs under minimal exertion. Heart transplantation improves quality of life and has survival rates at 1, 3, and 5 years of about 91%, 85%, and 78%, respectively.[1,] The number of candidates for transplants exceeds the supply of donor organs; thus the interest in the development of mechanical devices.

Devices and Regulatory Status

A number of implantable ventricular assist devices (VADs) and artificial heart systems have been FDA approved through a Humanitarian Device Exemption, 510(k), or premarket approval regulatory pathway. This section discusses currently marketed devices.
FDA maintains a list of recent device recalls at https://www.fda.gov/medical-devices/medical-device-recalls/2021-medical-device-recalls

Ventricular Assist Devices

Implantable VADs are attached to the native heart, which may have enough residual capacity to withstand a device failure in the short term. In reversible heart failure conditions, the native heart may regain some function, and weaning and explanting of the mechanical support system after months of use has been described. VADs can be classified as internal or external, electrically or pneumatically powered, and pulsatile or continuous-flow. Initial devices were pulsatile, mimicking the action of a beating heart. More recent devices may use a pump, which provides continuous flow. Continuous devices may move blood in a rotary or axial flow.

Surgically implanted VADs represent a method of providing mechanical circulatory support for patients not expected to survive until a donor heart becomes available for transplant or for whom transplantation is contraindicated or unavailable. VADs are most commonly used to support the left ventricle but right ventricular and biventricular devices may be used. The device is larger than most native hearts, and therefore the size of the patient is an important consideration; the pump may be implanted in the thorax or abdomen or remain external to the body. Inflow to the device is attached to the apex of the failed ventricle, while outflow is attached to the corresponding great artery (aorta for the left ventricle, a pulmonary artery for the right ventricle). A small portion of the ventricular wall is removed for insertion of the outflow tube; extensive cardiotomy affecting the ventricular wall may preclude VAD use.

The intent of treatment may evolve over the course of treatment; for example, there is not necessarily a strict delineation between bridge to transplant and destination therapy, and transplant eligibility can change.

Table 1 lists the VADs currently available in the US. The HeartWare VAD System was discontinued in June 2021 due to evidence from observational studies demonstrating a higher frequency of neurological adverse events and mortality with the system compared to other commercially available LVADs.

Table 1. Available Ventricular Assist Devices

Device	Manufacturer	Approval Date	FDA Clearance	PMA, HDE, or 510(k) No.	Indication
Thoratec IVAD	Thoratec	Aug 2004	PMA Supp	P870072	Bridge to transplant and postcardiotomy
DeBakey VAD Child	MicroMed	Feb 2004	HDE	H030003	Bridge to transplant in children 5-16 y
HeartMate II	Thoratec	Apr 2008	PMA	P060040	Bridge to transplant and destination
CentriMag	Thoratec	Dec 2019	PMA	P170038	Postcardiotomy, bridge to decision
Berlin Heart EXCOR Pediatric VAD	Berlin	Jun 2017	PMA	P160035	Bridge to transplant
HeartMate 3 Left Ventricular Assist System	Thoratec	Aug 2017 Oct 2018	PMA PMA	P160054 P160054/S008	Bridge to transplant Destination

FDA: U.S. Food and Drug Administration; HDE: humanitarian device exemption; PMA: premarket approval; VAD: ventricular assist device.

Total Artificial Heart

The total artificial heart (TAH)is a biventricular device that completely replaces the function of the diseased heart. An internal battery requires frequent recharging from an external power source. Many systems use a percutaneous power line, but a transcutaneous power-transfer coil allows for a system without lines traversing the skin, possibly reducing the risk of infection. Because the native heart must be removed, failure of the device is synonymous with cardiac death.
Currently the Syncardia Temporary Total Artificial Heart (Syncardia Systems) is the only Total Artificial Heart available in the US (Table 2). The AbioCor Total Artificial Heart was FDA approved under the Humanitarian Device Exemption program in 2006, but is no longer being marketed or in development.

Table 2. Available Total Artificial Heart

Device	Manufacturer	Approval Date	FDA Clearance	PMA No.	Indication
SynCardia Temporary Total Artificial Heart(Formerly CardioWest Total Artificial Heart and	SynCardia Systems	2004	510(k)	P030011	Bridge to transplant in cardiac transplant-eligible candidates at risk of imminent death from biventricular failure.

Jarvik Total Artificial Heart)					

FDA: U.S. Food and Drug Administration; PMA: premarket approval.

Percutaneous Ventricular Assist Devices

Some circulatory assist devices are placed percutaneously (i.e., are not implanted). They may be referred to as pVADs. Two different pVADs have been developed, the TandemHeart and the Impella device (Table 3). In the TandemHeart System, a catheter is introduced through the femoral vein and passed into the left atrium via transseptal puncture. Oxygenated blood is then pumped from the left atrium into the arterial system via the femoral artery. The Impella device is introduced through a femoral artery catheter. In this device, a small pump is contained within the catheter placed into the left ventricle. Blood is pumped from the left ventricle, through the device, and into the ascending aorta. Devices in which most of the system's components are external to the body are for short-term use (6 hours to 14 days) only, due to the increased risk of infection and need for careful, in-hospital monitoring. Adverse events associated with pVAD include access site complications such as bleeding, aneurysms, or leg ischemia. Cardiovascular complications can also occur, such as perforation, myocardial infarction, stroke, and arrhythmias.

Table 3. Available Percutaneous Ventricular Assist Devices

Device	Manufacturer	Approval Date	FDA Clearance	PMA, 510(k) No.	Indication
TandemHeart	Cardiac Assist	Sep 2011	510(k)	K110493	Temporary left ventricular bypass of ≤6 h
Impella Recover LP 2.5	Abiomed	May 2008	510(k)	K063723	Partial circulatory support using extracorporeal bypass control unit for ≤6 h
Impella 2.5 System	Abiomed	Mar 2015	PMA	P140003	Temporary ventricular support for ≤6 h

FDA: U.S. Food and Drug Administration; PMA: premarket approval.

POLICY

A. Postcardiotomy Setting/Bridge to Recovery

1. Implantable ventricular assist devices with U.S. Food and Drug Administration (FDA) approval or clearance may be considered **medically necessary** in the postcardiotomy setting in patients who are unable to be weaned off cardiopulmonary bypass.

B. Bridge to Transplantation

1. Implantable ventricular assist devices with FDA approval or clearance may be considered **medically necessary** as a bridge to heart transplantation for patients who are currently listed as heart transplantation candidates and not expected to survive until a donor heart can be obtained, or are undergoing evaluation to determine candidacy for heart transplantation.

2. Implantable ventricular assist devices with FDA approval or clearance, including humanitarian device exemptions, may be considered **medically necessary** as a bridge to heart transplantation in children 16 years old or younger who are currently listed as heart transplantation candidates and not expected to survive until a donor heart can be obtained, or are undergoing evaluation to determine candidacy for heart transplantation.

3. Total artificial hearts with FDA-approved devices may be considered **medically necessary** as a bridge to heart transplantation for patients with biventricular failure who have no other reasonable medical or surgical treatment options, who are ineligible for other univentricular or biventricular support devices, and are currently listed as heart transplantation candidates or are undergoing evaluation to determine candidacy for heart transplantation, and not expected to survive until a donor heart can be obtained.

C. Destination Therapy

1. Implantable ventricular assist devices with FDA approval or clearance may be considered **medically necessary** as destination therapy with end-stage heart failure patients who meet the following:

   a) New York Heart Association (NYHA) Class III heart failure with dyspnea upon mild physical activity or NYHA Class IV; **AND**

   b) Left ventricular ejection fraction ≤ 25%; **AND**

   c) Inotrope-dependent; OR cardiac index <2.2 liters/min/m^2, while not on inotropes and also meeting **ONE** of the following:

      1) On optimal medical management, based on current heart failure practice guidelines for at least 45 of the last 60 days and are failing to respond

      OR

      2) Advanced heart failure for at least 14 days and dependent on intra-aortic balloon pump for ≥7 days.

D. Percutaneous ventricular assist devices are intended for partial circulatory support for a limited time period. The use of an FDA-approved percutaneous ventricular assist device may be considered **medically necessary** for short-term stabilization of patients with ANY of the following indications:

1. Cardiogenic shock that is refractory to medications and intra-aortic balloon pump (IABP); OR

2. Cardiogenic shock, as an alternative to IABP; OR

3. High-risk patients undergoing invasive cardiac / electrophysiological procedures who need circulatory support (see Policy Guidelines #6).

E. Percutaneous ventricular assist devices are considered **experimental / investigational** for all other indications.

F. Other Indications

1. Other applications of implantable ventricular devices or total artificial hearts are considered **experimental / investigational**, including, but not limited to, the use ***of*** total artificial hearts as destination therapy.

2. The use of non-FDA approved or cleared implantable ventricular assist devices or total artificial hearts is considered **experimental / investigational**.

Policy Guidelines

1. Only 2 VADs have approval from FDA for the pediatric population. The DeBakey VAD Child device and the Berlin Heart EXCOR Pediatric VAD have FDA approval through the HDE process. The DeBakey VAD is indicated for use in children ages 5 to 16 years who are awaiting a heart transplant, ie, as a bridge to transplant while the Berlin Heart EXCOR VAD is indicated for children with severe isolated left ventricular or biventricular dysfunction who are candidates for cardiac transplant and require circulatory support.

2. In general, candidates for bridge-to-transplant implantable VADs are those who are considered appropriate heart transplant candidates but who are unlikely to survive the waiting period until a human heart donor is available. Some studies have included the following hemodynamic selection criteria: either a left atrial pressure of 20 mm Hg or a cardiac index of less than 2.0 L/min/m^2 while receiving maximal medical support. Patients with VADs are classified by the United Network for Organ Sharing as status I, that is, persons who are most ill and are considered the highest priority for transplant.

3. The median duration for time on the device is between 20 and 120 days.

4. Contraindications for bridge to transplant VADs and TAH include conditions that would generally exclude patients for heart transplant. Such conditions are chronic irreversible hepatic, renal, or respiratory failure; systemic infection; coagulation disorders, and inadequate psychosocial support. Due to potential problems with adequate function of the

VAD or TAH, implantation is also contraindicated in patients with uncorrected valvular disease.

5. In addition, patients must have sufficient space in the thorax and/or abdominal cavity for the device. In the case of the CardioWest™ temporary Total Artificial Heart, this excludes patients with body surface areas less than 1.7 m^2 or who have a distance between the sternum and 10th anterior rib of less than 10 cm, as measured by computed tomography scan.

6. High risk patients are defined as patients with a combination of left ventricular dysfunction with an ejection fraction <35% combined with high risk coronary anatomy (severe left main stenosis OR extensive triple vessel coronary disease OR target vessel supplying >40% of the viable myocardium).

RATIONALE

This evidence review has been updated regularly with searches of the PubMed database. The most recent literature update was performed through June 28, 2021.

Evidence reviews assess the clinical evidence to determine whether the use of technology improves the net health outcome. Broadly defined, health outcomes are the length of life, quality of life (QOL), and ability to function-including benefits and harms. Every clinical condition has specific outcomes that are important to patients and managing the course of that condition. Validated outcome measures are necessary to ascertain whether a condition improves or worsens; and whether the magnitude of that change is clinically significant. The net health outcome is a balance of benefits and harms.

To assess whether the evidence is sufficient to draw conclusions about the net health outcome of technology, 2 domains are examined: the relevance, and quality and credibility. To be relevant, studies must represent 1 or more intended clinical use of the technology in the intended population and compare an effective and appropriate alternative at a comparable intensity. For some conditions, the alternative will be supportive care or surveillance. The quality and credibility of the evidence depend on study design and conduct, minimizing bias and confounding that can generate incorrect findings. The randomized controlled trial (RCT) is preferred to assess efficacy; however, in some circumstances, nonrandomized studies may be adequate. RCTs are rarely large enough or long enough to capture less common adverse events and long-term effects. Other types of studies can be used for these purposes and to assess generalizability to broader clinical populations and settings of clinical practice.

This literature review assesses 3 devices: (1) ventricular assist devices (VADs), (2) total artificial hearts (TAHs), and (3) percutaneous VADs (pVADs). This review addresses the short-term use of the devices as a bridge to recovery or transplantation. Left VADs (LVADs) and TAHs are also evaluated as longer-term destination therapies for patients who are not transplant candidates.

Ventricular Assist Devices

Clinical Context and Therapy Purpose

The purpose of VADs in patients who have end-stage heart failure is to provide a treatment option that is an alternative to or an improvement on existing therapies.

The question addressed in this evidence review is: Does the use of a VAD improve the net health outcome in individuals with end-stage heart failure?

The following PICO was used to select literature to inform this review.

Population

The relevant population of interest is individuals with end-stage heart failure.
There are 4 categories of use for ventricular assist devices. However, these categories may overlap, as the intent of using a VAD may evolve over the course of treatment. Recently the concept of short and long term mechanical circulatory support has been used to describe the overlap across these indications.

Bridge to transplant: Use of a VAD to sustain life until a donor heart becomes available.
Destination therapy: Permanent use of the device, typically for patients ineligible for transplantation.

Bridge to recovery: Use of a VAD results in restoration of myocardial function, sufficient that heart transplant is not needed.

Bridge to decision: Use of a VAD in an attempt reverse secondary organ dysfunction that is a contraindication to transplant. However, these cases are often characterized as destination therapy rather than bridge to decision

Interventions

The therapy being considered is a VAD.

Comparators

The comparator of interest is optimal medical management, including use of an intra-aortic balloon pump when indicated.

Outcomes

The general outcomes of interest are overall survival (OS), survival to transplant,transplant outcomes, device malfunction or replacement, infection, and quality of life (QOL).
Time-to-transplant is of interest, as is the short-term outcome ranging from 30 days to 1 year.
When VAD is used as destination therapy, the time of interest ranges from 6 months to 2 years following implantation.

Study Selection Criteria

To assess efficacy outcomes, we included comparative controlled prospective trials, with preference for randomized controlled trials

In the absence of such trials, we included comparative observational studies, with a preference for prospective studies.

To assess longer term outcomes and adverse effects, we included single-arm studies that captured longer periods of follow up and/or larger populations.

Within each category of study design, studies with larger sample size studies and longer duration were prioritized.

We excluded studies with duplicative or overlapping populations.

Review of Evidence

Ventricular Assist Devices as Bridge to Heart Transplant in Adults

The insertion of a VAD will categorize its recipient as a high-priority heart transplant candidate. The available evidence on the efficacy of VADs in bridging patients with refractory heart failure to transplant includes single-arm series, which generally have reported high success rates in bridging to transplant.

Systematic Reviews

Older systematic reviews concluded that VADs can provide an effective bridge to transplantation.[2,3,]

Randomized Controlled Trial

The Multicenter Study of MagLev Technology in Patients Undergoing Mechanical Circulatory Support Therapy with HeartMate 3 (MOMENTUM 3) trial compared HeartMate 3 centrifugal continuous-flow device with the HeartMate II axial continuous-flow device in patients indicated for circulatory support as a bridge to transplant or destination therapy; inclusion criteria included: 1) New York Heart Association (NYHA) Class III heart failure with dyspnea upon mild physical activity or NYHA Class IV; 1) left ventricular ejection fraction ≤ 25%; 3) inotrope-dependent OR cardiac index <2.2 liters/min/m^2 while not on inotropes plus on optimal medical management for at least 45 of the last 60 days and failing to respond or with advanced heart failure for at least 14 days and dependent on intra-aortic balloon pump for ≥7 days. HeartMate 3 received premarket approval (PMA) as a bridge to transplant therapy in August 2017 and as destination therapy in October 2018. The destination therapy indication was based on 2-year results from MOMENTUM 3, which showed superiority of the HeartMate 3 device compared to HeartMate II on the composite primary outcome, survival at 2 years free of disabling stroke or reoperation to replace a malfunctioning device (relative risk 0.84; 95% confidence interval [CI], 0.78–0.91, p<.001).[4,] Prevalence of stroke at 2 years was lower in the HeartMate 3 than the HeartMate 2 group (10.1% vs 19.2%; p=.02).[5,] Measures of functional capacity and Health-Related QOL did not differ between the 2 devices at 6 months.[6,]

A prespecified subgroup analysis of MOMENTUM 3 published in 2020 did not find differences in outcomes based on preoperative categories of bridge to transplant, bridge to transplant candidacy, or destination therapy. [7,]

Nonrandomized Studies

Slaughter et al (2013) reported combined outcomes for patients included in the HeartWare bridge to transplant study and a continued-access protocol granted by the FDA.[8,] The study included 322 patients with heart failure, eligible for a heart transplant, who received the HeartWare (140 patients from the original study; 190 patients in the continue-access protocol who were monitored to the outcome or had completed 180-day follow-up at the time of analysis). Survival rates at 60, 180, and 360 days were 97%, 91%, and 84%, respectively. The most common adverse events were respiratory dysfunction, arrhythmias, sepsis, and driveline exit-site infections. Patients generally had improvements in QOL measures. (Note: The HeartWare VAD System was discontinued in June 2021 due to evidence from observational

studies demonstrating a higher frequency of neurological adverse events and mortality with the system compared to other commercially available LVADs.)

Strueber et al (2011) published a case series of 50 patients awaiting heart transplantation treated with HeartWare Ventricular Assist System, which is a smaller, continuous-flow centrifugal device implanted in the pericardial space.[9,] Patients were followed until transplantation, myocardial recovery, device explant, or death. The median duration of time on the VAD was 322 days. Nine patients died: 3 from sepsis, 3 from multiple organ failure, and 4 from hemorrhagic stroke. At the end of follow-up, 20 (40%) patients had undergone transplant, 4 (8%) had had the pump explanted, and the remaining 17 (34%) continued on pump support. The most common complications were infection and bleeding: 21 (42%) patients had infections, 5 (10%) had sepsis, while 15 (30%) patients had bleeding complications, 10 (20%) of whom required surgery. (Note: The HeartWare VAD System was discontinued in June 2021 due to evidence from observational studies demonstrating a higher frequency of neurological adverse events and mortality with the system compared to other commercially available LVADs.)

Aaronson et al (2012) reported on results of a multicenter, prospective study of the HeartWare device. The study enrolled 140 patients awaiting heart transplantation who underwent HeartWare implantation. A control group of 499 subjects comprised patients drawn from the Interagency Registry for Mechanically Assisted Circulatory Support (INTERMACS) database, which collects data on patients who receive FDA approved durable mechanical circulatory support (MCS) devices. The study's primary outcome was defined as survival on the originally implanted device, transplantation, or explantation for ventricular recovery at 180 days. Secondary outcomes were comparisons of survival between groups and functional, QOL, and adverse event outcomes in the HeartWare group. Success on the primary outcome occurred in 90.7% of the HeartWare group and 90.1% of controls ($p<.001$, noninferiority with a 15% margin). Serious adverse events in the HeartWare group included, most commonly, bleeding, infections, and perioperative right heart failure. (Note: The HeartWare VAD System was discontinued in June 2021 due to evidence from observational studies demonstrating a higher frequency of neurological adverse events and mortality with the system compared to other commercially available LVADs.)

In 5 reports published from 2007 to 2008, with sample sizes ranging from 32 to 279 patients, most participants received the continuous-flow device as a bridge to transplantation.[10,11,12,13,14,] Survival rates at 6 months ranged between 67% and 87%, and between 50% and 80% at 1 year. These rates were similar to those reported from the INTERMACS registry.[15,] A study by Patel et al (2008) compared HeartMate I with HeartMate II recipients at a single-center, finding similar rates of 1 year survival and subsequent development of right heart failure.[13,] Serious adverse events occurring after HeartMate II implantation included bleeding episodes requiring reoperation, stroke, infection, and device failure.

Aissaoui et al (2018) published an observational study comparing 224 patients in Germany and France with end-stage heart failure who received a VAD (group I, n=83) or heart transplantation or medical therapy as first treatment options (group II, n=141).[16,] The estimated 2-year survival was 44% for group I and 70% for group II ($p<.001$).

Reports from registries of patients who received the HeartMate 3 device have been published recently. Schmitto et al (2019) reported 2-year outcomes in 50 patients who received the device as a bridge to transplant.[17,] Survival rates at 6 months, 1 year, and 2 years were 92%, 81%, and

74%, respectively, and the total stroke rate over 2 years was 24%. Gustafsson et al (2018) reported 6-month outcomes of 482 patients; 66% of patients received the VAD as a bridge to transplant, 26% as destination therapy, 2% as a bridge to recovery, and 6% as a bridge to transplant candidacy or decision. Results were not separately reported by indication.[18,] The 6-month survival rate was 82% (95% CI 79% to 85%). Three patients received a transplant. The incidence of stroke was 6.1%. Pagani et al (2021) used Medicare claims data to analyze survival outcomes in patients who received different LVADs between January 2014 and December 2018, with followup through December 2019.[19,] Of 4195 patients who received implants, there were 117 (14.3%) deaths among 821 Heartmate3 patients, 375 (20.4%) deaths among 1840 Heartmate II patients, and 375 (24.5%) deaths among 1534 patients with other VADs. The adjusted hazard ratio for mortality at 1-year (confirmed in a propensity score matched analysis) for the HeartMate 3 versus HeartMate II was 0.64 (95% CI; 0.52 to 0.79, p<.0001) and for the HeartMate 3 versus other-VADs was 0.51 (95% CI; 0.42 to 0.63, p<.0001).

Ventricular Assist Devices as Destination Therapy for End-Stage Heart Failure in Adults

Systematic Reviews

The evaluation of VADs as destination therapy was informed by a TEC Assessment (2002) that offered the following observations and conclusions[20,]:

- The available evidence comes from a single, well-designed and rigorously conducted randomized trial, Randomized Evaluation of Mechanical Assistance for the Treatment of Congestive Heart Failure, known as the REMATCH study.[21,] The trial was a cooperative effort of Thoratec, Columbia University, and the National Institutes of Health.
- The trial found that patients with end-stage heart failure who are not candidates for cardiac transplantation had significantly better survival on a VAD compared with treatment by optimal medical therapy. Median survival was improved by approximately 8.5 months. Serious adverse events were more common in the VAD group but they appear to be outweighed by this group's better outcomes on function; New York Heart Association functional class was significantly improved, as was the QOL among those living to 12 months.
- VAD patients spent a greater relative proportion of time inside the hospital than medical management patients did but the survival advantage would mean a longer absolute time outside the hospital.

Park et al (2005) published reports on the extended 2-year follow-up of patients from the REMATCH trial, which found that survival and QOL benefits were still apparent.[22,23,] In addition, their reports and other case series have suggested continuing improvement in outcomes related to ongoing improvements in the device and patient management. However, the durability of the HeartMate device used in the REMATCH trial was a concern (eg, at a participating institution, all 6 long-term survivors required device change-outs).

Randomized Controlled Trials

The MOMENTUM 3 trial compared HeartMate 3 centrifugal continuous-flow device with the HeartMate II axial continuous-flow device in patients indicated for circulatory support as a bridge to transplant or destination therapy; inclusion criteria included 1) NYHA Class III heart failure with dyspnea upon mild physical activity or NYHA Class IV; 1) left ventricular ejection fraction ≤ 25%; 3) inotrope-dependent OR cardiac index <2.2 liters/min/m^2 while not on inotropes plus on optimal medical management for at least 45 of the last 60 days and failing to respond or with

advanced heart failure for at least 14 days and dependent on intra-aortic balloon pump for ≥7 days. HeartMate 3 received PMA approval as a bridge to transplant therapy in August 2017 and as destination therapy in October 2018. The destination therapy indication was based on 2-year results from MOMENTUM 3, which showed superiority of the HeartMate 3 device compared to HeartMate II on the composite primary outcome, survival at 2 years free of disabling stroke or reoperation to replace a malfunctioning device (relative risk 0.84; 95% CI, 0.78–0.91, p<.001).[4,] Prevalence of stroke at 2 years was lower in the HeartMate 3 than the HeartMate 2 group (10.1% vs 19.2%; p=.02).[5,] Measures of functional capacity and Health-Related QOL did not differ between the 2 devices at 6 months.[6,]

A prespecified subgroup analysis of MOMENTUM 3 published in 2020 did not find differences in outcomes based on preoperative categories of bridge to transplant, bridge to transplant candidacy, or destination therapy. Additionally, nearly 15% of those initially deemed transplant ineligible were eventually transplanted within 2 years of follow-up, supporting that clinical categorizations based on transplant eligibility should no longer be used.[7,]

The ENDURANCE trial compared the HeartWare centrifugal continuous-flow device with the HeartMate II axial continuous-flow device in patients indicated for circulatory support as destination therapy.[24,] Both trials found the centrifugal device to be noninferior to the axial device for the primary, composite outcome including measures of survival, freedom from disabling stroke, and freedom from device failure. While there are fewer device failures with the centrifugal devices without a significant increase in disabling stroke, the HeartWare device was associated with increased risk of any stroke over a period of 2 years. (Note: The HeartWare VAD System was discontinued in June 2021 due to evidence from observational studies demonstrating a higher frequency of neurological adverse events and mortality with the system compared to other commercially available LVADs.)

Nonrandomized Studies

A prospective observational study called the Risk Assessment and Comparative Effectiveness of Left Ventricular Assist Device and Medical Management in Ambulatory Heart Failure Patients (ROADMAP) study, reported by Estep et al (2015), compared LVAD support (n=97) with optimal medical therapy (n=103) for patients with heart failure not requiring inotropes and found superior survival and health-related QOL in LVAD-treated patients.[25,] Twelve-month, as-treated, event-free actutimes survival was 80% in the LVAD group and 63% in the best medical therapy group (p=.022). Two-year results were reported by Starling et al (2017).[26,] At the end of 2 years, 35 (34%) medical therapy patients and 60 (62%) LVAD patients were alive on their original therapy; 23 medical management patients received LVADs during the 2 years. The LVAD-treated patients continued to have higher as-treated, event-free actutimes survival (70% vs 41%, p<.001), although there was no statistical difference in intention-to-treat survival (70% vs 63%, p=.31).

In an FDA required postapproval study of the HeartMate II device for destination therapy,[27,] which included the first 247 HeartMate II patients identified as eligible for the device as destination therapy, Jorde et al (2014) found that outcomes and adverse events did not differ significantly from those of the original trial, which compared patients who received the HeartMate II with earlier-generation devices. Survival rates in the postapproval cohort were 82% and 69% at 1 and 2 years postoperatively, respectively.

After the release of the REMATCH trial results, Rogers et al (2007) published results from a prospective, nonrandomized trial comparing LVAD as destination therapy with optimal medical therapy for patients with heart failure who were not candidates for a heart transplant.[28,] Fifty-five patients who had NYHA functional class IV symptoms and who failed to wean from inotropic support were offered a Novacor LVAD; 18 did not receive a device due to preference or device unavailability and served as a control group. The LVAD-treated patients had superior survival rates at 6 months (46% vs 22%; p=.03) and 12 months (27% vs 11%; p=.02), along with fewer adverse events.

Arnold et al (2016) analyzed 1638 patients receiving LVADs as destination therapy between May 2012 and September 2013. Results were selected from the INTERMACS registry and assessed for poor outcomes. Poor outcome was defined as death or mean Kansas City Cardiomyopathy Questionnaire overall score less than 45 throughout the year after implantation. Analyses included inverse probability weighting to adjust for missing data. About 22.4% of patients died within the first year after implantation, and an additional 7.3% had persistently poor QOL; 29.7% met the definition of poor outcome. Poor outcomes were more common in those patients having higher body mass indices, lower hemoglobin levels, previous cardiac surgery, history of cancer, severe diabetes, and poorer QOL preimplant.

Ventricular Assist Devices as Bridge to Recovery in Adults
Nonrandomized Studies
VADs may have a role in bridging patients to recovery, particularly if there is reverse remodeling of the left ventricle. Several studies have investigated the role of VADs in bridging patients to decision for transplant eligibility. One clearly defined population in which the potential for myocardial recovery exists is in the postcardiotomy setting.

Acharya et al (2016) reported on patients who underwent VAD placement for acute myocardial infarction (AMI) who were enrolled in the INTERMACS registry, a prospective national registry of FDA approved durable MCS devices.[29,] Patients who had an AMI as the admitting diagnosis or a major myocardial infarction (MI) as a hospital complication that resulted in VAD implantation (n=502) were compared with patients who underwent VAD implantation for non-AMI indications (n=9727). Patients in the AMI group were generally sicker at baseline, with higher rates of smoking, severe diabetes, and peripheral vascular disease but had fewer cardiac surgeries and recent cardiovascular hospitalizations. Most AMI patients (53.8%) were implanted with a "bridge to candidacy" strategy. At 1 month post-VAD, 91.8% of the AMI group were alive with the device in place. At 1 year post-VAD, 52% of the AMI group were alive with the device in place, 25.7% had received a transplant, 1.6% had their VAD explanted for recovery, and 20.7% died with the device in place.

Two additional 2016 publications from the INTERMACS registry reported on cardiac recovery in patients implanted with LVADs. Wever-Pinzon et al (2016) included adults registered between March 2006 and June 2015 excluding those who had a right VAD only, TAH, or prior heart transplant (n=15631). One hundred twenty-five of these patients had an a priori bridge to recovery LVAD strategy. Cardiac recovery occurred in 192 (1.3%) of the LVAD patients overall and in 14 (11.2%) of the bridge to recovery patients. Topkara et al (2016) reported a similar analysis of 13454 INTERMACS adults with implants between June 2006 and June 2015 without TAH or pulsatile-flow LVAD or heart transplant. Device explant rates for cardiac recovery were

0.9% at 1-year, 1.9% at 2-year, and 3.1% at 3-year follow-up. An additional 9% of patients demonstrated partial cardiac recovery.

In a prospective multicenter study to assess myocardial recovery in patients with LVAD implantation as a bridge to transplant, Maybaum et al (2007) evaluated 67 patients with heart failure who had LVAD implantation for severe heart failure.[30,] After 30 days, patients demonstrated significant improvements compared with their pre-LVAD state in left ventricular ejection fraction (17.1% vs 34.12%, p<.001), left ventricular end-diastolic diameter (7.1 cm vs 5.1 cm, p<.001), and left ventricular mass (320 g vs 194 g, p<.001), respectively. However, only 9% of patients recovered sufficiently to have their LVAD explanted.

Agrawal et al (2018) conducted a retrospective cohort study evaluating the 30-day readmissions of 2510 patients undergoing LVAD implantation.[31,] Of the patients who met the inclusion criteria, 788 (31%) were readmitted within 30 days after surviving initial index hospitalization. Cardiac causes accounted for 23.8% of readmissions, 13.4% due to heart failure, and 8.1% to arrhythmias. Infection (30.2%), bleeding (17.6%), and device-related causes (8.2%) comprised the 76.2% of noncardiovascular causes for readmission.

Ventricular Assist Devices in Pediatric Patients

The FDA approved EXCOR Pediatric VAD is available for use as a bridge to cardiac transplant in children. The FDA approval was based on data from children who were part of the initial clinical studies of this device.[32,] Publications have reported positive outcomes for children using VADs as a bridge to transplantation.

Comparative Studies

Bulic et al (2017) identified all U.S. children between 1 and 21 years of age at heart transplant between 2006 and 2015 who had dilated cardiomyopathy and were supported with an LVAD or vasoactive infusions alone at the time of transplant from the Organ Procurement and Transplant Network registry (N=701).[33,] Functional status as measured by the median Karnofsky Performance Scale score at heart transplant was higher for children receiving LVAD (6) compared with vasoactive infusion (5; p<.001) and children receiving LVAD were more likely to be discharged from the hospital at the time of transplant. The percentage of children having a stroke at the time of transplant was higher in those receiving LVAD (3% vs 1%, p=.04).

Wehman et al (2016) reported on posttransplant survival outcomes for pediatric patients who received a VAD, extracorporeal membrane oxygenation (ECMO), or no MCS, in the pretransplant period.[34,] The study included 2777 pediatric patients who underwent heart transplant from 2005 to 2012 who were identified through the United Network for Organ Sharing database, of whom 428 were bridged with VADs and 189 were bridged with ECMO. In unadjusted analysis, the actutimes 5-year survival rate was highest in the direct-to-transplant group (77%), followed by the VAD group (49%) and then the ECMO group (35%). In a proportional hazards model to predict time to death, restricted to the first 4 months posttransplant, ECMO bridging was significantly associated with a higher risk of death (adjusted hazard ratio, 2.77 vs direct-to-transplant; 95% CI , 2.12 to 3.61; p<.001). However, a model to predict time to death excluding deaths in the first 4 months posttransplant, the bridging group was not significantly associated with risk of death.

Fraser et al (2012) evaluated the EXCOR device among 48 children, ages 16 or younger, with 2-ventricle circulation who had severe heart failure, despite optimized treatment, and were listed for a heart transplant.[35,] Patients were divided into 2 groups based on body surface area; a historical control group of children receiving circulatory support with ECMO from the Extracorporeal Life Support Organization registry were matched in a 2:1 fashion with study participants based on propensity-score matching. For participants in cohort 1 (body surface area <0.7 m^2), the median survival time had not been reached at 174 days, while in the matched ECMO comparison group, the median survival was 13 days (p<.001). For participants in cohort 2 (body surface area range, 0.7 to <1.5 m^2), the median survival was 144 days compared with 10 days in the matched ECMO group (p<.001). Rates of adverse events were high in both EXCOR device cohorts, including major bleeding (cohort 1, 42%; cohort 2, 50%), infection (cohort 1, 63%; cohort 2, 50%), and stroke (29% of both cohorts).

Noncomparative Studies

Blume et al (2016) published the first analysis of the Pediatric Interagency Registry for Mechanical Circulatory Support, which is a prospective, multicenter registry that collects data on patients who are under age 19 years at the time of implant, and includes those implanted with either durable or temporary VADs.[36,] At analysis, the registry included 241 patients; of them, 41 were implanted with a temporary device only, leaving 200 patients implanted with VADs for this study. Most patients (73%) had an underlying diagnosis of cardiomyopathy. At the time of implantation, 64% were listed for transplant, while 29% were implanted with a "bridge to candidacy" strategy. A total of 7% were implanted with a destination therapy strategy. Actutimes survival at both 6 months and 1 year was 81%. By 6 months, 58% of patients had received transplants.

Almond et al (2013) reported results from a prospective, multicenter registry to evaluate outcomes in children who received the EXCOR device as a bridge to transplant.[37,] This study included a broader patient population than the Fraser et al (2012) study (discussed above). All patients were followed from the time of EXCOR implantation until transplantation, death, or recovery. The study included 204 children, 67% of whom received the device under compassionate use. Survival at 12 months on EXCOR support was 75%, including 64% who survived to transplantation, 6% who recovered (device explanted and the patient survived 30 days), and 5% who were alive with the device in place. In a follow-up study that evaluated 204 children from the same registry, Jordan et al (2015) reported relatively high rates of neurologic events in pediatric patients treated with the EXCOR device (29% of patients), typically early in the course of device use.[38,]

Chen et al (2016) reported on a retrospective, single-center series of pediatric patients with continuous-flow VADs, with a focus on outpatient experiences.[39,] The series included 17 children implanted with an intracorporeal device from 2010 to 2014. Eight (47%) patients were discharged after a median postimplant hospitalization duration of 49 days. Adverse events were common in outpatients, most frequently major device malfunction (31% [5/16] events) and cardiac arrhythmias (31% [5/16] events). At the time of analysis, 4 patients had received an orthotopic heart transplant, 2 were on ongoing support, and 1 each had been transferred or died.

Another retrospective, single-center series of pediatric patients, conducted by Conway et al (2016), reported on outcomes with short-term continuous-flow VADs, including the Thoratec PediMag or CentriMag, or the Maquet RotaFlow.[40,] From 2015 to 2014, 27 children were

supported with 1 of these devices, most commonly for congenital heart disease (42%). The median duration of support was 12 days, and 67% of all short-term continuous-flow VAD runs (19 of 28 runs) led to hospital discharge.

Effects of Pretransplant Ventricular Assist Devices on Transplant Outcomes
Published studies continue to report that the use of a VAD does not compromise the success of a subsequent heart transplant and, in fact, may improve posttransplant survival, thus improving the use of donor hearts.[41,42,43,44,] A systematic review by Alba et al (2011) examined the evidence on the effect of VADs on posttransplant outcomes.[45,] Reviewers included 31 observational studies that compared transplant outcomes in patients who did and did not have pretransplant VAD. Survival at 1 year was more likely in patients who had VAD treatment, but this benefit was specific to patients who received an intracorporeal device (relative risk, 1.8; 95% CI, 1.53 to 2.13). For patients treated with an extracorporeal device, the likelihood of survival did not differ from patients not treated with a VAD (relative risk, 1.08; 95% CI, 0.95 to 1.22). There was no difference in the risk of rejection rates between patients who did and did not receive LVAD treatment.

Deo et al (2014) reported no significant differences in outcomes for 37 bridge to transplant patients with a VAD and 70 patients who underwent a heart transplant directly.[46,] Data from the United Network for Organ Sharing Network, reported by Grimm et al (2016), suggested that patients bridged to transplant with an LVAD have better outcomes than those bridged with TAHs or biventricular assist devices.[47,] Using the United Network for Organ Sharing database, Davies et al (2008) reported on the use of VADs in pediatric patients undergoing heart transplantation.[48,] Their analysis concluded that pediatric patients requiring a pretransplantation VAD have long-term survival similar to those not receiving MCS.

Section Summary: Ventricular Assist Devices
In adults, the evidence on the efficacy of VADs as a bridge to transplant consists of controlled trials comparing different VADs, uncontrolled trials, registry studies, and case series.
The highest-quality evidence on the efficacy of LVADs as destination therapy in patients who are not transplant candidates is the REMATCH trial. This multicenter RCT reported that the use of LVADs led to improvements in survival, QOL, and functional status. A more recent trial comparing VADs has broader inclusion criteria and supports that criteria move away from use of transplant ineligibility, as treatment may evolve over the course of treatment. This evidence supports that health outcomes are improved with LVADs in this patient population.

Questions remain about defining and identifying the population most likely to experience cardiac recovery with VAD placement. One clearly defined population in which the potential for myocardial recovery exists is in the postcardiotomy setting. The current evidence is insufficient to identify other heart failure patient populations that might benefit from the use of an LVAD as a specific bridge to recovery treatment strategy.

The evidence in children, mainly from registry studies, demonstrates the effectiveness of pediatric devices as a bridge to heart transplant.

Total Artificial Heart
Clinical Context and Therapy Purpose

The purpose of a TAH in patients who have end-stage heart failure is to provide a treatment option that is an alternative to or an improvement on existing therapies.

The question addressed in this evidence review is: Does the use of a TAH improve the net health outcome in individuals with end-stage heart failure?

The following PICO was used to select literature to inform this review.

Population

The relevant population of interest are individuals with end-stage heart failure.

Interventions

The therapy being considered is a TAH used as a bridge to heart transplant or as destination therapy.

Comparators

The comparator of interest is optimal medical therapy without a TAH.

Outcomes

The general outcomes of interest are overall survival (OS), survival to transplant, transplant outcomes, device malfunction or replacement, infection, and quality of life.
Time-to-transplant is of interest, as is the short-term outcome ranging from 30 days to 1 year. When TAH is used as destination therapy, the time of interest ranges from 6 months to 2 years following implantation.

Study Selection Criteria

To assess efficacy outcomes, we included comparative controlled prospective trials, with preference for randomized controlled trials

In the absence of such trials, we included comparative observational studies, with a preference for prospective studies.

To assess longer term outcomes and adverse effects, we included single-arm studies that captured longer periods of follow up and/or larger populations.

Within each category of study design, studies with larger sample size studies and longer duration were prioritized.

We excluded studies with duplicative or overlapping populations.

Review of Evidence

Total Artificial Heart as a Bridge to Transplant for End-Stage Heart Failure

Nonrandomized Studies

The FDA approval of the CardioWest TAH was based on the results of a nonrandomized, prospective study of 81 patients.[49,] Patients had failed inotropic therapy, had a biventricular failure, and thus were not considered appropriate candidates for an LVAD. The rate of survival to transplant was 79%, which was considered comparable with the experience with LVAD in patients with left ventricular failure. The mean time from entry into the study until transplantation or death was 79.1 days.

Case series have been reported on outcomes for the TAH as a bridge to transplant. For example, Copeland et al (2012) reported on 101 patients treated with the SynCardia artificial heart as a bridge to transplant.[50,] All patients either met established criteria for MCS or were failing medical therapy on multiple inotropic drugs. Mean support time was 87 days (range, 1-441 days). The rate of survival to transplant was 68.3% (69/101). Of the 32 deaths before the transplant, 13 were due to multiorgan failure, 6 were due to pulmonary failure, and 4 were due to neurologic injury. Survival rates after transplant at 1, 5, and 10 years, respectively, were 76.8%, 60.5%, and 41.2%.

Total Artificial Heart as Destination Therapy for End-Stage Heart Failure
Case Series
Data on the artificial heart are available from the FDA approval information[51,] and from a published article describing results for the first 7 patients.[52,] The FDA indicated that its decision on the AbioCor implantable heart was based on the manufacturer's (Abiomed) laboratory and animal testing and on a small clinical study of 14 patients conducted by Abiomed. Study participants had a 1-month survival prognosis of not more than 30%, were ineligible for cardiac transplants, and were not projected to benefit from VAD therapy. The study showed that the device was safe and likely to benefit people with severe heart failure whose death was imminent and for whom no alternative treatments were available. Of the 14 patients studied, 12 survived the surgery. Mean duration of support for the patients was 5.3 months. In some cases, the device extended survival by several months (survival was 17 months in 1 patient). Six patients were ambulatory; 1 patient was discharged home. Complications included postoperative bleeding and neurologic events. No device-related infections were reported.

Torregrossa et al (2014) reported on 47 patients who received a TAH at 10 worldwide centers and had the device implanted for more than 1 year.[53,] Patients were implanted for dilated cardiomyopathy (n=23), ischemic cardiomyopathy (n=15), and "other" reasons (n=9). Over a median support time of 554 days (range, 365-1373 days), 34 (72%) patients were successfully transplanted, 12 (24%) patients died while on device support, and 1 (2%) patient was still supported. Device failure occurred in 5 (10%) patients. Major complications were common, including systemic infection in 25 (53%) patients, driveline infections in 13 (27%) patients, thromboembolic events in 9 (19%) patients, and hemorrhagic events in 7 (14%) patients. Two of the deaths occurred secondary to device failure.

Section Summary: Total Artificial Heart
There is less evidence on the use of TAH as a bridge to transplant compared with the use of LVADs. The type of evidence on a bridge to transplant is similar to that for LVADs (ie, case series reporting substantial survival rates in patients without other alternatives). Therefore, similar to LVADs, this evidence is sufficient to conclude that TAH improves outcomes for these patients and TAH is a reasonable alternative for patients who require a bridge to transplantation but who are ineligible for other types of life-prolonging support devices.

There is less evidence on the use of TAH as destination therapy compared with the use of LVADs. Although TAHs show promise as destination therapy in patients who have no other treatment options, the available data on their use is extremely limited. Currently, the evidence base is insufficient to support conclusions about TAH efficacy in this setting.

Percutaneous Ventricular Assist Devices for Cardiogenic Shock

Clinical Context and Therapy Purpose
The purpose of pVADs in patients who have cardiogenic shock is to provide a treatment option that is an alternative to or an improvement on existing therapies.
The question addressed in this evidence review is: Does the use of a pVAD improve the net health outcome in individuals with cardiogenic shock?

The following PICO was used to select literature to inform this review.
Population
The relevant population of interest are individuals with cardiogenic shock.

Interventions
The therapy being considered is pVADs.

Comparators
The comparator of interest is intra-aortic balloon pump (IABP).

Outcomes
The general outcomes of interest are OS, device malfunction, heart failure, respiratory dysfunction, arrhythmias, and infection.

Timing of interest ranges from perioperative events to 30-day mortality outcomes.

Study Selection Criteria
To assess efficacy outcomes, we included comparative controlled prospective trials, with preference for randomized controlled trials

In the absence of such trials, we included comparative observational studies, with a preference for prospective studies.

To assess longer term outcomes and adverse effects, we included single-arm studies that captured longer periods of follow up and/or larger populations.

Within each category of study design, studies with larger sample size studies and longer duration were prioritized.

We excluded studies with duplicative or overlapping populations.

Review of Evidence
Systematic Reviews
Romeo et al (2016) reported on a systematic review and meta-analysis that evaluated various percutaneous mechanical support methods, including pVADs, for patients with cardiogenic shock due to AMI who were undergoing revascularization (Tables 4 and 5).[54,] Reviewers included 3 RCTs (described below) comparing pVADs with IABPs, along with 3 comparative observational studies. A major limitation noted by the review authors was the small sample size of the RCTs. Observational studies were included in meta-analyses, with subgroup analyses by study design reported (see Table 4). In the comparison of pVADs with IABP, reviewers found that in-hospital mortality (the primary outcome of the analysis) was nonsignificantly increased in the pVAD group. Subgroup analysis did not find significant differences in estimates from RCTs and

observational studies, and CIs overlapped. There was no significant heterogeneity within RCTs or observational studies. The relative risk reduction was -17.23%, translating to 8 more deaths per every 100 patients treated with pVADs instead of IABP.

Table 4. Characteristics of a Systematic Review Evaluating pVADs vs IABPs for Cardiogenic Shock

Study	Dates	Trials	Participants	N	Design
Romeo et al (2016)[54,]	1997-2015	6	Patients receiving IABP or pVADs	271	3 RCT and 3 observational

pVAD: percutaneous ventricular assist device; IABP: intra-aortic balloon pump; RCT: randomized controlled trial.

Table 5. Results of a Systematic Review Evaluating pVADs vs IABPs for Cardiogenic Shock

Study	In Hospital Mortality
Romeo et al (2016)[54,]	
RCTs	
Total N	100
Risk ratio (95% CI)	1.06 [0.68, 1.66]
I^2 (p)	0% (.83)
Observational Studies	
Total N	171
Risk ratio (95% CI)	1.16 (0.92, 1.47)
NNH per 100 patients	8
I^2 (p)	0% (.062)
All studies	
Total N	271
Risk ratio	1.14 (0.93, 1.41)
I^2 (p)	0% (.92)

pVAD: percutaneous ventricular assist device; IABP: intra-aortic balloon pump; N: sample size; CI: confidence interval; NNH: number needed to harm; RCT: randomized controlled trial.

Randomized Controlled Trials

A total of 4 RCTs have compared pVADs with IABPs for patients who had cardiogenic shock; 3 were included in the Romeo et al (2016) systematic review described above[55,56,57,] and 1was published after Romeo et al (2016).[57,] The 4 RCTs enrolled a total of 148 patients, 77 treated with a pVAD and 71 treated with an IABP. All 4 trial populations included patients with AMI and cardiovascular shock; 1 trial restricted its population to patients who were postrevascularization in the AMI setting. The primary outcomes reported were 30-day mortality, hemodynamic measures of left ventricle pump function, and adverse events. The trials are summarized in Tables 6 and 7. Some trials reported improvements in hemodynamic and metabolic parameters

but none found any reductions in 30-day mortality. The IMPella versus IABP Reduces mortality in STEMI patients treated with primary percutaneous coronary intervention (PCI) in Severe cardiogenic SHOCK (IMPRESS) trial reported 6-month mortality outcomes and also found no difference between groups. Bleeding events and leg ischemia were more common in the pVAD groups.

Table 6. Characteristics of RCTs Evaluating pVADs and IABPs for Cardiogenic Shock

Study (Registration)	Countries	Sites	Dates	pVAD	Key Eligibility Criteria
Ouweneel et al (2017)[57,]IMPRESS(NTR3450)	Netherlands, Norway	2	2012-2015	Impella CP	AMI and severe CS in the setting of immediate PCI; receiving mechanical ventilation
Seyfarth et al (2008)[56,]ISAR-SHOCK(NCT00417378)	Germany	2	2004-2007	Impella LP 2.5	AMI <48 h and CS
Burkhoff et al (2006)[55,]TandemHeart	U.S.	12	2002-2004	TandemHeart	CS <24 h due to MI or heart failure
Thiele et al (2005)[58,]	Germany	1	2000-2003	TandemHeart	AMI with CS and intent to revascularize with PCI

AMI: acute myocardial infarction; CS: cardiogenic shock; IABP: intra-aortic balloon counterpulsation; IMPRESS: IMPella versus IABP Reduces mortality in STEMI patients treated with primary PCI in Severe cardiogenic SHOCK; ISAR-SHOCK: Efficacy Study of LV Assist Device to Treat Patients With Cardiogenic Shock; MI: myocardial infarction; PCI: percutaneous coronary intervention; pVAD: percutaneous ventricular assist device; RCT; randomized controlled trial.

Table 7. Results of RCTs Evaluating pVADs and IABPs for Cardiogenic Shock

Study	30-Day Mortality	60-day Mortality	Bleeding	Leg Ischemia	Other Outcomes
Ouweenel et al (2017)[57,] IMPRESS					*Rehospitalization*
N	48	48	48		48
pVAD	46%	50%	33%		21%
IABP	50%	50%	8%		4%
HR (95% CI)	0.96 (0.42 to 2.18)	1.04 (0.47 to 2.32)			
Seyfarth et al (2008)[56,] ISAR-SHOCK					*Increase in cardiac index* (L/min/m^2)
N	26			26	26
pVAD	46%			8%	0.49
IABP	46%			0%	0.11
Burhkoff et al (2006)[55,]TandemHeart					At least 1 adverse event:
N	33		33	33	33
pVAD	47%		42%	21%	95%

Study	30-Day Mortality	60-day Mortality	Bleeding	Leg Ischemia	Other Outcomes
IABP	36%		14%	14%	71%
Thiele et al (2005)[58,]					*Final cardiac index* (W/m^2)
N	41		41	41	41
pVAD	43%		90%	33%	0.37
IABP	45%		40%	0%	0.28

CI: confidence interval; HR: hazard ratio; IABP: intra-aortic balloon counterpulsation; IMPRESS: IMPella versus IABP Reduces mortality in STEMI patients treated with primary PCI in Severe cardiogenic SHOCK; ISAR-SHOCK: Efficacy Study of LV Assist Device to Treat Patients With Cardiogenic Shock; pVAD: percutaneous ventricular assist devices; RCT: randomized controlled trial.

[a] Values are hazard ratio (95% confidence interval).

[b] Major bleeding.

Nonrandomized Studies

Results of a recent comparative observational study conducted by Schrage et al (2019) were consistent with previous evidence in showing no mortality benefit for pVAD over IABP.[59,] Using registry data, the researchers retrospectively identified 237 patients who had been treated with the Impella device and matched them to patients who had received IABP as part of an RCT. There was no significant difference between groups in 30-day all-cause mortality (48.5% vs 46.4%, p=.64). Severe or life-threatening bleeding (8.5% vs 3.0%, p<.01) and peripheral vascular complications (9.8% vs 3.8%, p=.01) occurred significantly more often in the Impella group.

Case series of patients treated with pVADs as an alternative to IABP in cardiogenic shock have reported high success rates as a bridge to alternative therapies.[60,61,62,63,64,65,] However, given the availability of RCT evidence, these studies add little to the body of evidence on the efficacy of pVADs for the management of cardiogenic shock.

Section Summary: Percutaneous Ventricular Assist Devices for Cardiogenic Shock

Four RCTs comparing pVAD with IABP in patients with cardiogenic shock failed to demonstrate a mortality benefit for pVAD use and reported higher complication rates associated with pVAD use. Comparative observational studies were consistent with the RCT evidence.

Percutaneous Ventricular Assist Devices for High-Risk Cardiac Procedures

Clinical Context and Therapy Purpose

The purpose of pVADs in patients who undergo high-risk cardiac procedures is to provide a treatment option that is an alternative to or an improvement on existing therapies.

The question addressed in this evidence review is: Does the use of a pVAD improve the net health outcome in in patients who undergo high-risk cardiac procedures?

The following PICO was used to select literature to inform this review.

Population

The relevant population of interest are individuals undergoing high-risk cardiac procedures.

Interventions
The therapy being considered is pVADs.

Comparators
The comparator of interest is intra-aortic balloon pump (IABP).

Outcomes
The general outcomes of interest are OS, device malfunction, heart failure, respiratory dysfunction, arrhythmias, and infection.

Timing of interest ranges from perioperative events to 30-day mortality outcomes.

Study Selection Criteria
To assess efficacy outcomes, we included comparative controlled prospective trials, with preference for randomized controlled trials

In the absence of such trials, we included comparative observational studies, with a preference for prospective studies.

To assess longer term outcomes and adverse effects, we included single-arm studies that captured longer periods of follow up and/or larger populations.

Within each category of study design, studies with larger sample size studies and longer duration were prioritized.

We excluded studies with duplicative or overlapping populations.

Review of Evidence
Percutaneous Ventricular Assist Devices as Ancillary Support for High-Risk Percutaneous Coronary Intervention
Systematic Reviews
Two recent systematic reviews have evaluated pVAD as ancillary support for patients undergoing high-risk PCI. Table 8 shows a comparison of the RCTs included in each. Only 1 RCT (PROTECT II) was included in both reviews. In addition to PROTECT II, Ait Ichou et al (2018) included 3 RCTs in patients who received emergent PCI post-MI: IMPRESS, IMPRESS in STEMI, and ISAR-SHOCK. Ait Ichou et al (2018) conducted a systematic review of the Impella device compared to IABP for high-risk patients undergoing PCI (Tables 8 and 9).[66,] The researchers included 4 RCTs, 2 controlled observational studies, and 14 uncontrolled observational studies published between 2006 and 2016, with a total of 1287 patients. Individual study results were reported with no pooled analyses.

Table 8. Comparison of RCTs Included in SRs Evaluating pVAD as Ancillary Support for High-Risk PCI

Study[2]	Ait Ichou et al (2018)[66,]	Briasoulis et al (2016)[67,]
O'Neill et al (2012)[68,] PROTECT II	●	●
Ouweneel et al 2016[57,]IMPRESS	●	

Study[2]	Ait Ichou et al (2018)[66,]	Briasoulis et al (2016)[67,]
Ouweneel et al (2016)IMPRESS in STEMI[65,]	●	
Seyfarth et al (2008)[56,]ISAR-SHOCK	●	

RCT: randomized controlled trial; SR: systematic review; pVAD: percutaneous ventricular assist device; PCI: percutaneous coronary intervention.

The range of results identified in the controlled and uncontrolled studies as reported by Ait Ichou et al (2018) are summarized in Table 10. The RCTs found similar rates of all-cause mortality between the Impella device and IABP. One RCT reported higher rates among patients randomized to Impella (7.6% vs 5.9%) but the difference was not statistically significant (p=.47). Two of the 3 controlled observational studies found higher 30-day mortality rates in patients receiving Impella but the differences were not statistically significant. There was a reduction in major cardiovascular adverse events at 90 days with the Impella device reported in 1 RCT (odds ratio vs IABP: 0.79, 95% CI: 0.64–0.96). Among uncontrolled studies, the rates of all-cause mortality and adverse events were heterogeneous due to differences in study populations and their underlying cardiovascular risk.

Risk of bias assessment determined that 3 of the 4 RCTs were at a low-risk of bias, but they had insufficient power to detect a difference in clinical outcomes. One RCT (IMPRESS in STEMI) was rated as a high-risk of bias due to early termination and widening of inclusion criteria over time. The 2 controlled observational studies had methodological limitations leading to a serious risk of bias, and the other observational studies were at a high-risk of bias due to their uncontrolled study design. After exclusion of low-quality studies, the rates of 30-day mortality, major bleeding, and MI did not change substantially. However, in the group of low-risk of bias studies, the vascular complication rate was higher.

An earlier systematic review and meta-analysis conducted by Briasoulis et al (2016) included studies of both Impella and TandemHeart.[67,] Reviewers identified 18 nonrandomized observational studies and a single RCT (PROTECT II).[68,]. Results are shown in Table 9. In the observational studies, the sample sizes ranged from 7 to 637 patients. In a pooled analysis of the observational trial data, the 30-day mortality rate following Impella-assisted high-risk PCI was 3.5% (95% CI, 2.2% to 4.8%; I^2=20%), while that for TandemHeart-assisted high-risk PCI was 8% (95% CI, 2.9% to 13.1%; I^2=55%). The pooled vascular complication rates were 4.9% (95% CI, 2.3% to 7.6%) and 6.5% (95% CI, 3.2% to 9.9%) for the Impella and the TandemHeart, respectively. This meta-analysis did not compare pVAD to IABP or other interventions.

Table 9. Characteristics of SRs Evaluating pVAD as Ancillary Support for High-Risk PCI

Study	Dates	Trials	Participants	Devices Included	N (Range)	Design	Duration
Ait Ichou et al (2018)[66,]	Inception-2016	20	High-risk patients undergoing PCI	Impella	1287 (10-225)	4 RCT, 2 controlled observational, 14 uncontrolled observational	1-42 months

Study	Dates	Trials	Participants	Devices Included	N (Range)	Design	Duration
Briasoulis et al (2016)[67,]		Impella: 12TandemHeart::8	High-risk patients undergoing PCI	Impella and TandemHeart	Impella: 1350 (10-637)TandemHeart: 252 (7-68)	Impella:TandemHeart:	Impella:TandemHeart:

N: sample size; PCI: percutaneous coronary intervention; pVAD: percutaneous ventricular assist device; RCT: randomized controlled trial; SR: systematic review.

Table 10. Results of SRs Evaluating pVAD as Ancillary Support for High-Risk Percutaneous Coronary Intervention

Study	All-Cause Mortality (30 days)	All-Cause Mortality (3 months)	All-Cause Mortality (12 months)	Stroke (30 days)	Stroke (3 months)	Stroke (12 months)	Major Adverse Events (30 days)	Major Adverse Events (3 months)	Major Adverse Events (12 months)	Vascular Complications
Ait Ichou et al (2018)										
Range of effect (controlled studies)										
Impella	7.6%-46%	12.1%-50%	15.3%-26%	0%	0.9%-8%	8%	15%-35.1%	26%-40.6%	37%	
IABP	0%-46%	8.7%-50%	11%-25.8%	0%-1.8%	0%-4%	0%	40%-40.1%	33%-49.3%	47%	
Range of effect (uncontrolled studies)										
Impella	0%-74%	--	10%-45.5%	0%-2%	--	--	0%-20%	--	30%	
Briasoulis et al (2016)[67,]							*Major bleeding*			
Impellla	54/1346						126/1346			89/1346
Pooled effect (95% CI)	0.35 (0.022, 0.048)						0.71 (0.043, 0.99)			0.049 (0.023, 0.076)

Study	All-Cause Mortality (30 days)	All-Cause Mortality (3 months)	All-Cause Mortality (12 months)	Stroke (30 days)	Stroke (3 months)	Stroke (12 months)	Major Adverse Events (30 days)	Major Adverse Events (3 months)	Major Adverse Events (12 months)	Vascular Complications
I^2 (p)	20% (.243)						63% (.002)			78% (<.001)
TandemHeart	22/212						11/205			15/205
Pooled effect (95% CI)	0.080 (0.029, 0.131)						0.036 (0.011, 0.061)			0.065 (0.032, 0.099)
I^2 (p)	55% (.030)						0% (.581)			0% (.865)

CI: confidence interval; IABP: intra-aortic balloon pump; pVAD: percutaneous ventricular assist device; SR: systematic review.

High-Risk Ventricular Tachycardia Ablation

Reddy et al (2014) reported on outcomes for a series of 66 patients enrolled in a prospective, multicenter registry who underwent ventricular tachycardia (VT) ablation with a pVAD or IABP.[69,] Twenty-two patients underwent ablation with IABP assistance, while 44 underwent ablation with the TandemHeart or Impella pVAD device (non-IABP group). Compared with patients who received support with an IABP, those who received support with a pVAD had more unstable VTs that could be mapped and ablated (1.05 vs 0.32, p<.001), more VTs than could be terminated by ablation (1.59 vs 0.91, p=.001), and fewer VTs terminated with rescue shocks (1.9 vs 3.0, p=.049). More pVAD-supported patients could undergo entrainment/activation mapping (82% vs 59%, p=.046). Mortality and VT recurrence did not differ over the study follow-up (average, 12 months).

In a retrospective study, Aryana et al (2014) reported procedural and clinical outcomes for 68 consecutive unstable patients with scar-mediated epicardial or endocardial VT who underwent ablation with or without pVAD support.[70,] Thirty-four patients had hemodynamic support periprocedurally with a pVAD. Percutaneous VAD- and non-pVAD-supported patients had similar procedural success rates. Compared with non-pVAD-supported patients, patients in the pVAD group had a longer maximum time in unstable VT (27.4 minutes vs 5.3 minutes, p<.001), more VT ablations per procedure (1.2 vs 0.4, p<.001), shorter radiofrequency ablation time (53 seconds vs 68 seconds, p=.022), and a shorter hospital length of stay (4.1 days vs 5.4 days, p=.013). Over a follow-up of 19 months, rates of VT recurrence did not differ between groups.

Section Summary: Percutaneous Ventricular Assist Devices for High-Risk Cardiac Procedures

RCTs, controlled and uncontrolled observational studies, and systematic reviews of these studies have not demonstrated a benefit of pVAD used as ancillary support for patients undergoing high-risk PCI.

Two nonrandomized studies have compared VT ablation with pVAD or IABP. In both studies, patients who had pVAD support spent less time in unstable VT than patients without pVAD support. Rates of recurrence of VT was comparable between groups for both studies. The current evidence-based does not support conclusions about the use of pVAD for VT ablation.

Percutaneous Ventricular Assist Devices for Cardiogenic Shock Refractory to Intra-Aortic Balloon Pump Therapy

Clinical Context and Therapy Purpose

The purpose of pVADs in patients who undergo high-risk cardiac procedures is to provide a treatment option that is an alternative to or an improvement on existing therapies.
The question addressed in this evidence review is: Does the use of a pVAD improve the net health outcome in in patients with cardiogenic shock refractory to IABP therapy?

The following PICO was used to select literature to inform this review.

Population

The relevant population of interest is individuals with cardiogenic shock refractory to IABP therapy.

Interventions

The therapy being considered is pVADs.

Comparators

The comparator of interest is optimal medical therapy without IABP and other MCS.

Outcomes

The general outcomes of interest are OS, device malfunction, heart failure, respiratory dysfunction, arrhythmias, and infection.
Timing of interest ranges from perioperative events to 30-day mortality outcomes.

Study Selection Criteria

To assess efficacy outcomes, we included comparative controlled prospective trials, with preference for randomized controlled trials

In the absence of such trials, we included comparative observational studies, with a preference for prospective studies.

To assess longer term outcomes and adverse effects, we included single-arm studies that captured longer periods of follow up and/or larger populations.
Within each category of study design, studies with larger sample size studies and longer duration were prioritized.

We excluded studies with duplicative or overlapping populations.

Review of Evidence

Nonrandomized Studies

In a large series, Kar et al (2011) treated 117 patients who had severe, refractory cardiogenic shock with the TandemHeart System.[71,] Eighty patients had ischemic cardiomyopathy and 37 had nonischemic cardiomyopathy. There were significant improvements in all hemodynamic measures

following LVAD placement. For example, the cardiac index increased from 0.52 L/min/m^2 to 3.0 L/min/m^2 ($p<.001$), and systolic blood pressure increased from 75 mm Hg to 100 mm Hg ($p<.001$). Complications were common after LVAD implantation. Thirty-four (29.1%) patients had bleeding around the cannula site, and 35 (29.9%) developed sepsis during hospitalization. Groin hematoma occurred in 6 (5.1%) patients; limb ischemia in 4 (3.4%) patients; femoral artery dissection or perforation in 2 (1.7%) patients; stroke in 8 (6.8%) patients; and coagulopathy in 13 (11.0%) patients.

Section Summary: Percutaneous Ventricular Assist Devices for Cardiogenic Shock Refractory to Intra-Aortic Balloon Pump Therapy
Percutaneous VADs have been assessed in uncontrolled studies of patients with cardiogenic shock including those refractory to IABP therapy. The case series have reported high rates of adverse events that may outweigh any potential benefits. As a result, the evidence on pVADs does not demonstrate that the use of VADs is associated with improvements in health outcomes for patients with cardiogenic shock refractory to IABP therapy.

Summary of Evidence

Ventricular Assist Device

For individuals who have end-stage heart failure who receive a VAD as a bridge to transplant, the evidence includes single-arm trials and observational studies. Relevant outcomes are overall survival (OS), symptoms, functional outcomes, QOL , and treatment-related mortality and morbidity. There is a substantial body of evidence from clinical trials and observational studies supporting implantable VADs as a bridge to transplant in patients with end-stage heart failure, possibly reducing mortality as well as improving QOL. These studies have reported that substantial numbers of patients have survived to transplant in situations in which survival would not be otherwise expected. The evidence is sufficient to determine that the technology results in an improvement in the net health outcome.

For individuals who have end-stage heart failure who receive a VAD as destination therapy, the evidence includes a trial and multiple single-arm studies. Relevant outcomes are OS, symptoms, functional outcomes, QOL, and treatment-related mortality and morbidity. A well-designed trial with 2 years of follow-up data has demonstrated an advantage of implantable VADs as destination therapy for patients ineligible for a heart transplant. Despite an increase in adverse events, both mortality and QOL appear to be improved for these patients. A more recent trial comparing VADs has broader inclusion criteria and supports that criteria move away from use of transplant ineligibility, as treatment may evolve over the course of treatment. The evidence is sufficient to determine that the technology results in an improvement in the net health outcome.

Total Artificial Heart

For individuals who have end-stage heart failure who receive a TAH as a bridge to transplant, the evidence includes case series. Relevant outcomes are OS, symptoms, functional outcomes, QOL, and treatment-related mortality and morbidity. Compared with VADs, the evidence for TAHs in these settings is less robust. However, given the lack of medical or surgical options for these patients and the evidence case series provide, TAH is likely to improve outcomes for a carefully selected population with end-stage biventricular heart failure awaiting transplant who are not appropriate candidates for a left VAD. The evidence is sufficient to determine that the technology results in an improvement in the net health outcome.

For individuals who have end-stage heart failure who receive a TAH as destination therapy, the evidence includes 2 case series. Relevant outcomes are OS, symptoms, functional outcomes, QOL, and treatment-related mortality and morbidity. The body of evidence for TAHs as destination therapy is too limited to draw conclusions. The evidence is insufficient to determine that the technology results in an improvement in the net health outcome.

Percutaneous Ventricular Assist Device
For individuals with cardiogenic shock or who undergo high-risk cardiac procedures who receive a pVAD, the evidence includes RCTs , observational studies, and systematic reviews. Relevant outcomes are OS, symptoms, morbid events, functional outcomes, QOL, and treatment-related mortality and morbidity. Four RCTs of pVAD versus intra-aortic balloon pump for patients in cardiogenic shock failed to demonstrate a mortality benefit and reported higher complication rates with pVAD use. Comparative observational studies were consistent with the RCT evidence. RCTs, controlled and uncontrolled observational studies, and systematic reviews of these studies have not demonstrated a benefit of pVAD used as ancillary support for patients undergoing high-risk cardiac procedures. The evidence is insufficient to determine that the technology results in an improvement in the net health outcome.

For individuals with cardiogenic shock refractory to intra-aortic balloon pump therapy who receive a pVAD, the evidence includes case series. Relevant outcomes are OS, symptoms, morbid events, functional outcomes, QOL, and treatment-related mortality and morbidity. Case series of patients with cardiogenic shock refractory to intra-aortic balloon pump have reported improved hemodynamic parameters following pVAD placement. However, these uncontrolled series do not provide evidence that pVADs improve mortality, and high rates of complications have been reported with pVAD use. The evidence is insufficient to determine that the technology results in an improvement in the net health outcome.

SUPPLEMENTAL INFORMATION
The purpose of the following information is to provide reference material. Inclusion does not imply endorsement or alignment with the evidence review conclusions.

Clinical Input From Physician Specialty Societies and Academic Medical Centers
While the various physician specialty societies and academic medical centers may collaborate with and make recommendations during this process, through the provision of appropriate reviewers, input received does not represent an endorsement or position statement by the physician specialty societies or academic medical centers, unless otherwise noted.

2014 Input
In response to requests, input was received from 2 physician specialty societies and 5 academic medical centers while this policy was under review in 2014. Vetting focused on the use of percutaneous ventricular assist devices (pVADs) under the American Heart Association and American College of Cardiology guidelines (2013) and on the use of the total artificial heart as destination therapy. All providing input supported the use of implantable VADs as destination therapy subject to the guidelines in the policy statements. Most providing input considered total artificial hearts to be investigational for destination therapy; reviewers noted that there are limited clinical trial data to support the use of total artificial hearts as destination therapy. Most providing input considered pVADs to be investigational as a "bridge to recovery" or "bridge to decision" and for all other indications. Some reviewers noted that pVADs may improve

patients' hemodynamics better than other alternatives, such as an intra-aortic balloon pump, but are associated with more complications. Some noted that, despite a lack of evidence to indicate that pVADs improve overall outcomes, there may be cases when pVADs may be considered to support intervention or treatment for a life-threatening condition.

Practice Guidelines and Position Statements

Guidelines or position statements will be considered for inclusion in 'Supplemental Information' if they were issued by, or jointly by, a US professional society, an international society with US representation, or National Institute for Health and Care Excellence (NICE). Priority will be given to guidelines that are informed by a systematic review, include strength of evidence ratings, and include a description of management of conflict of interest.

American Association for Thoracic Surgery/International Society for Heart and Lung Transplantation

In 2020, the American Association for Thoracic Surgery and the International Society for Heart and Lung Transplantation published guidelines on selected topics in mechanical circulatory support, including recommendations on the use of pVADs (Table 11).[72,] The guideline authors noted, "Compared with IABP [intraaortic balloon pump], contemporary percutaneous circulatory support devices provide a significant increase in cardiac index and mean arterial pressure; however, reported 30-day outcomes are similar."

Table 11. 2020 Guidelines on Mechanical Circulatory Support

Recommendation	COE	LOE
"Percutaneous LV to aorta pumps of appropriate size should be considered for cardiogenic shock from primary LV failure."	IIA	B

COE: class of evidence; LOE: level of evidence; LV: left ventricular.

American College of Cardiology Foundation et al

In 2017, the American College of Cardiology Foundation, American Heart Association (AHA), and Heart Failure Society of American published a focused update of the 2013 recommendations released by the American College of Cardiology Foundation and AHA.[73,] Left ventricular assist device was 1 of several treatment options recommended for patients with refractory New York Heart Association class III or IV heart failure (stage D). If symptoms were not improved after guideline -directed management and therapy, which included pharmacologic therapy, surgical management and/or other devices, then a left ventricular assist device would be an additional treatment option.

The 2017 update focused on changes in sections regarding biomarkers, comorbidities, and prevention of heart failure, while many of the previous recommendations remained unchanged. The American College of Cardiology Foundation and AHA (2013) released guidelines for the management of heart failure that included recommendations related to the use of mechanical circulatory support (MCS), including both durable and nondurable MCS devices.[74,] The guidelines categorized pVADs and extracorporeal ventricular assist devices (VADs) as nondurable MCS devices. Table 12 provides class IIA guidelines on MCS devices.

Table 12. 2017 Guidelines on Mechanical Circulatory Support

Recommendation	COE	LOE
"MCS is beneficial in carefully selected patients with stage D HF/EF in whom definitive management (eg, cardiac transplantation) or cardiac recovery is anticipated or planned."	IIA	B
"Nondurable MCS, including the use of percutaneous and extracorporeal ventricular assist devices (VADs), is reasonable as a "bridge to recovery" or "bridge to decision" for carefully selected patients with HF/EF with acute, profound hemodynamic compromise."	IIA	B
"Durable MCS is reasonable to prolong survival for carefully selected patients with stage D HF/EF."	IIA	B

COE: class of evidence; HF/EF: heart failure with reduced ejection fraction; LOE: level of evidence; MCS: mechanical circulatory support.

The 2013 guidelines also noted:
"Although optimal patient selection for MCS remains an active area of investigation, general indications for referral for MCS therapy include patients with LVEF [left ventricular ejection fraction] <25% and NYHA [New York Heart Association] class III-IV functional status despite GDMT [guideline-directed medical therapy], including, when indicated, CRT [cardiac resynchronization therapy], with either high predicted 1- to 2-year mortality (eg, as suggested by markedly reduced peak oxygen consumption and clinical prognostic scores) or dependence on continuous parenteral inotropic support. Patient selection requires a multidisciplinary team of experienced advanced HF [heart failure] and transplantation cardiologists, cardiothoracic surgeons, nurses, and ideally, social workers and palliative care clinicians."

American Heart Association
In 2012, the AHA published recommendations for the use of MCS.[75,] These guidelines defined nondurable MCS as IABPs , extracorporeal membrane oxygenation, extracorporeal VADs, and pVADs. Table 13 lists recommendations made on indications for the use of MCS, including durable and nondurable devices.

Table 13. 2012 Guidelines on Mechanical Circulatory Support

Recommendation	COE	LOE
"MCS for BTT indication should be considered for transplant-eligible patients with end-stage HF who are failing optimal medical, surgical, and/or device therapies and at high risk of dying before receiving a heart transplantation."	I	B
"Implantation of MCS in patients before the development of advanced HF … is associated with better outcomes. Therefore, early referral of HF patients is reasonable."	IIA	B
"MCS with a durable, implantable device for permanent therapy or DT is beneficial for patients with advanced HF, high 1-year mortality resulting from HF, and the absence of other life-limiting organ dysfunction; who are failing medical, surgical, and/or device therapies; and who are ineligible for heart transplantation."	I	B
"Elective rather than urgent implantation of DT can be beneficial when performed after optimization of medical therapy in advanced HF patients who are failing medical, surgical, and/or device therapies."	IIA	C

Recommendation	COE	LOE
"Urgent nondurable MCS is reasonable in hemodynamically compromised HF patients with end-organ dysfunction and/or relative contraindications to heart transplantation/durable MCS that are expected to improve with time and restoration of an improved hemodynamic profile." "These patients should be referred to a center with expertise in the management of durable MCS and patients with advanced HF."	IIA I	C C
"Patients who are ineligible for heart transplantation because of pulmonary hypertension related to HF alone should be considered for bridge to potential transplant eligibility with durable, long-term MCS."	IIA	B

BTT: bridge to transplant; COE: class of evidence; DT: destination therapy; HF: heart failure; LOE: level of evidence; MCS: mechanical circulatory support.

Society for Cardiovascular Angiography and Interventions et al

In 2015, the Society for Cardiovascular Angiography and Interventions, the Heart Failure Society of America, the Society of Thoracic Surgeons, and the American College of Cardiology published a joint clinical expert consensus statement on the use of percutaneous MCS devices in cardiovascular care.[76,] This statement addressed IABPs , left atrial-to-aorta assist device (eg, TandemHeart), left ventricle-to-aorta assist devices (eg, Impella), extracorporeal membrane oxygenation, and methods of right-sided support. Specific recommendations were not made, but the statement reviews the use of MCS in patients undergoing high-risk percutaneous intervention, those with cardiogenic shock, and those with acute decompensated heart failure.

U.S. Preventive Services Task Force Recommendations

Not applicable.

Ongoing and Unpublished Clinical Trials

Some currently unpublished trials that might influence this review are listed in Table 14.

Table 14. Summary of Key Trials

NCT No.	Trial Name	Planned Enrollment	Completion Date
Ongoing			
NCT01633502	Effects of Advanced Mechanical Circulatory Support in Patients With ST Segment Elevation Myocardial Infarction Complicated by Cardiogenic Shock. The Danish Cardiogenic Shock Trial	360	Jan 2023
NCT01627821[a]	Evaluation of the Jarvik 2000 Left Ventricular Assist System With Post-Auricular Connector--Destination Therapy Study	350	Dec 2021
NCT02232659[a]	SynCardia 70cc Temporary Total Artificial Heart (TAH-t) for Destination Therapy (DT)	38	May 2022
NCT02326402[a]	THEME Registry: TandemHeart Experiences and Methods	450	Dec 2023

NCT No.	Trial Name	Planned Enrollment	Completion Date
NCT01187368[a]	Prospective Multi-Center Randomized Study for Evaluating the EVAHEART®2 Left Ventricular Assist System: the COMPETENCE Trial	399	Mar 2024
NCT02387112	Early Versus Emergency Left Ventricular Assist Device Implantation in Patients Awaiting Cardiac Transplantation	200	Dec 2022
NCT02892955[a]	MOMENTUM 3 CAP Multi-Center Study of MagLev Technology in Patients Undergoing MCS Therapy With HeartMate 3™ Continued Access Protocol	1685	Mar 2021
Unpublished			
NCT02468778[a]	Supporting Patients Undergoing HIgh-Risk PCI Using a High-Flow PErcutaneous Left Ventricular Support Device (SHIELD II)	716	Dec 2021 Suspended after a report of decreased impeller speed at the end of a procedure.
NCT02459054[a]	SynCardia 50cc Temporary Total Artificial Heart (TAH-t) as a Bridge to Transplant	72	Jul 2020 Terminated (50cc TAH-t received FDA approval March 5, 2020)

FDA: U.S. Food and Drug Administration; NCT: national clinical trial; PCI: percutaneous coronary intervention.
[a] Denotes industry-sponsored or cosponsored trial.

CODING

The following codes for treatment and procedures applicable to this policy are included below for informational purposes. Inclusion or exclusion of a procedure, diagnosis or device code(s) does not constitute or imply member coverage or provider reimbursement. Please refer to the member's contract benefits in effect at the time of service to determine coverage or non-coverage of these services as it applies to an individual member.

CPT/HCPCS

33927 Implantation of a total replacement heart system (artificial heart) with recipient cardiectomy
33928 Removal and replacement of total replacement heart system (artificial heart)
33929 Removal of a total replacement heart system (artificial heart) for heart transplantation (List separately in addition to code for primary procedure)

33975 Insertion of ventricular assist device; extracorporeal, single ventricle
33976 Insertion of ventricular assist device; extracorporeal, biventricular
33977 Removal of ventricular assist device; extracorporeal, single ventricle
33978 Removal of ventricular assist device; extracorporeal, biventricular
33979 Insertion of ventricular assist device, implantable intracorporeal, single ventricle
33980 Removal of ventricular assist device, implantable intracorporeal, single ventricle
33990 Insertion of ventricular assist device, percutaneous including radiological supervision and interpretation; arterial access only
33991 Insertion of ventricular assist device, percutaneous including radiological supervision and interpretation; both arterial and venous access, with transseptal puncture
33992 Removal of percutaneous ventricular assist device at separate and distinct session from insertion
33995 Insertion of ventricular assist device, percutaneous, including radiological supervision and interpretation; right heart, venous access only
33997 Removal of percutaneous right heart ventricular assist device, venous cannula, at separate and distinct session from insertion

0451T	Insertion or replacement of a permanently implantable aortic counterpulsation ventricular assist system, endovascular approach, and programming of sensing and therapeutic parameters; complete system
0452T	Insertion or replacement of a permanently implantable aortic counterpulsation ventricular assist system, endovascular approach, and programming of sensing and therapeutic parameters; aortic counterpulsation device and vascular hemostatic seal.
0453T	Insertion or replacement of a permanently implantable aortic counterpulsation ventricular assist system, endovascular approach, and programming of sensing and therapeutic parameters; mechano-electrical skin interface.
0454T	Insertion or replacement of a permanently implantable aortic counterpulsation ventricular assist system, endovascular approach, and programming of sensing and therapeutic parameters; subcutaneous electrode.
0455T	Removal of permanently implantable aortic counterpulsation ventricular assist system; complete system (aortic counterpulsation device, vascular hemostatic seal, mechano-electical skin interface and electrodes)
0456T	Removal of permanently implantable aortic counterpulsation ventricular assist system; aortic counterpulsation device and vascular hemostatic seal
0457T	Removal of permanently implantable aortic counterpulsation ventricular assist system; mechano-electrical skin interface
0458T	Removal of permanently implantable aortic counterpulsation ventricular assist system; subcutaneous electrode

0459T	Relocation of skin pocket with replacement of implanted aortic counterpulsation ventricular assist device, mechano-electrical skin interface and electrodes
0460T	Relocation of skin pocket with replacement of implanted aortic counterpulsation ventricular assist device, subcutaneous electrode
0461T	Relocation of skin pocket with replacement of implanted aortic counterpulsation ventricular assist device, aortic counterpulsation device
0462T	Programming device evaluation (in person) with iterative adjustment of the implantable mechano-electical skin interface and/or external driver to test the function of the device and select optimal permanent programmed values with analysis, including review and report, implantable aortic couterpulsation ventricular assist system, per day
0463T	Interrogation device evaluation (in person) with analysis, review and report, includes connection, recording and disconnection per patient encounter, implantable aortic counterpulsation ventricular assist system, per day

ICD-10 Diagnoses

I09.81	Rheumatic heart failure
I11.0	Hypertensive heart disease with heart failure
I13.0	Hypertensive heart and chronic kidney disease with heart failure and stage 1 through stage 4 chronic kidney disease, or unspecified chronic kidney disease
I13.2	Hypertensive heart and chronic kidney disease with heart failure and with stage 5 chronic kidney disease, or end stage renal disease
I50.1	Left ventricular failure, unspecified
I50.20	Unspecified systolic (congestive) heart failure
I50.21	Acute systolic (congestive) heart failure
I50.22	Chronic systolic (congestive) heart failure
I50.23	Acute on chronic systolic (congestive) heart failure
I50.30	Unspecified diastolic (congestive) heart failure
I50.31	Acute diastolic (congestive) heart failure
I50.32	Chronic diastolic (congestive) heart failure
I50.33	Acute on chronic diastolic (congestive) heart failure
I50.40	Unspecified combined systolic (congestive) and diastolic (congestive) heart failure
I50.41	Acute combined systolic (congestive) and diastolic (congestive) heart failure
I50.42	Chronic combined systolic (congestive) and diastolic (congestive) heart failure
I50.43	Acute on chronic combined systolic (congestive) and diastolic (congestive) heart failure
I97.0	Post cardiotomy syndrome

REVISIONS

07-18-2016	Policy published 06-08-2016. Policy effective 07-18-2016.
10-01-2016	Updated Description section.
	Updated Rationale section.
	Updated References section.
03-29-2017	Title revised from "Total Artificial Hearts and Implantable Ventricular Assist Devices".
	In Policy section: ▪ Added new Item D, "Percutaneous ventricular assist devices are intended for partial circulatory support for a limited period of time. The use of an FDA-approved percutaneous ventricular assist device may be considered medically necessary for short-term stabilization of patients with ANY of the following indications: 1. Cardiogenic shock that is refractory to medications and intra-aortic balloon pump (IABP); OR 2. Cardiogenic shock, as an alternative to IABP; OR 3. High-risk patients undergoing invasive cardiac / electrophysiological procedures who need circulatory support." ▪ In Item E, add "other" to read, "Percutaneous ventricular assist devices are considered experimental / investigational for all other indications." ▪ Previous Item D is now Item F. ▪ In Policy Guidelines, added new Item 6.
	Updated Rationale section.
	Updated References section.
10-01-2017	Updated Description section.
	Updated Rationale section.
	In Coding section: ▪ Revised nomenclature to ICD-10 code: I50.1.
	Updated References section.
01-01-2018	In Coding section: ▪ Added CPT codes: 33927, 33928, 33929. ▪ Added HCPCS code: Q0477. ▪ Removed CPT codes: 0051T, 0052T, 0053T.
10-01-2018	Updated Description section.
	Updated Rationale section.
	In Coding section: ▪ Removed HCPCS code: Q0477.
	Updated References section.
10-24-2018	In Policy section: ▪ In Item D 3, added "#6" to read, "High-risk patients undergoing invasive cardiac/electrophysiological procedures who need circulatory support (see Policy Guidelines #6)."
01-01-2019	In Coding section: ▪ Added new HCPCS code: L8698.
03-16-2021	Updated Description section.
	Updated Rationale section.
	In Coding section • Added CPT 33995, 33997, 0451T, 0452T, 0453T, 0454T, 0455T, 0456T, 0457T, 0458T, 0459T, 0460T, 0461T, 0462T, 0463T • Deleted CPT L8698
	Updated References section.

10-08-2021	Updated Description section
	In Policy section: Implantable ventricular assist devices with FDA approval or clearance may be considered **medically necessary** as destination therapy with end-stage heart failure patients who are ~~ineligible for human heart transplant and~~ who meet the following ~~REMATCH Study criteria~~: ~~New York Heart Association (NYHA) class IV heart failure for ≥60 days, OR~~ ~~patients in NYHA class III/IV for 28 days, received ≥14 days' support with intra-aortic balloon pump or dependent on IV inotropic agents, with 2 failed weaning attempts.~~ New York Heart Association (NYHA) Class III heart failure with dyspnea upon mild physical activity or NYHA Class IV; **AND** Left ventricular ejection fraction ≤ 25%; **AND** Inotrope-dependent; OR cardiac index <2.2 liters/min/m^2, while not on inotropes and also meeting **ONE** of the following: On optimal medical management, based on current heart failure practice guidelines for at least 45 of the last 60 days and are failing to respond **OR** Advanced heart failure for at least 14 days and dependent on intra-aortic balloon pump for ≥7 days
	Updated References section

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