Innovative devices for advanced heart failure: exploring the current state and future direction of device therapies

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Purpose of review
Despite improvements in medical and device therapies for the treatment of heart failure, the incidence and prevalence of heart failure continue to increase. Given the relative stagnation in new pharmacologic therapies, considerable attention has been given in recent years to device therapies to supplement care in patients with advanced heart failure. Recent successful clinical trial results with an angiotensin–neprilysin inhibitor are not expected to change this situation significantly; the drug has been shown to delay, not eliminate, the progression of heart failure. This review focuses on the technologies that are currently in development for the treatment of advanced heart failure.

Recent findings
Novel devices that involve electrical, neurohormonal or structural remodeling of the heart that can be inserted either percutaneously or with a minimally invasive surgery are currently at various stages of clinical development. All, however, have shown promising clinical results in preclinical and early clinical studies.

Summary
Novel device therapies for advanced heart failure continue to show promising clinical results. Randomized controlled trials are still needed to better evaluate their efficacy. Nevertheless, it can be anticipated that at least several of these devices will be among the armamentarium of treatment options for advanced heart failure in the future.

Keywords
cardiac remodeling, device therapy, heart failure

INTRODUCTION

Despite improvements in medical and device therapies for treating patients with advanced heart failure, the incidence and prevalence of heart failure continue to increase. An estimated 5.1 million adults in the United States have heart failure, and among adults over the age of 65 years, the incidence of heart failure is approaching 10 per 1000 population [1]. Medical management of chronic heart failure has led to significant improvements in morbidity and mortality [2]. Unfortunately, in the past 2 decades, there has been little advancement in novel drug targets in advanced heart failure with the notable exception of an angiotensin–neprilysin inhibitor [3▪].

Given the noted stagnation in pharmacologic growth, considerable attention has been given in recent years to device-based therapies to supplement care in patients with advanced heart failure. Cardiac resynchronization therapy (CRT) is the most well-known and successful device therapy in heart failure to date. CRT provides electromechanical coordination and improves ventricular synchrony by simultaneous pacing behind the left ventricle and in the right ventricular apex. CRT therapy has been shown to improve 6-min walk distance, rate of hospitalization for worsening heart failure, and survival in symptomatic patients with reduced ejection fraction and conduction delay [4,5]. Guidelines strongly recommend CRT for

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KEY POINTS

- Device therapy in advanced heart failure is in various stages of clinical development and works by promoting adaptive remodeling of the heart.
- Devices that apply electrical stimulation to various components of the cardiovascular system favorably rebalance the neurohormonal system in heart failure.
- Devices that alter the structural integrity of the heart in advanced heart failure allow more favorable reverse remodeling.

patients with a left bundle branch block pattern, left ventricular ejection fraction (LVEF) 35% or less, QRS duration at least 150 ms and New York Heart Association (NYHA) class III or IV symptoms [class I, level of evidence (LOE) A] or NYHA class II (class I, LOE B). Interestingly, CRT in patients with QRS duration less than 120 ms may actually worsen outcomes [6▪].

The success of CRT resulted in significant interest in development of device-based therapies for advanced heart failure. Several newer implantable devices and minimally invasive techniques aimed at disease modification are currently at varying stages of clinical evaluation. The remainder of this review will focus on the next generation of implantable devices that are currently being studied in heart failure.

ELECTRICAL REMODELING AND NEUROMODULATION

Devices that use electrical stimulation to alter the neurohormonal milieu of the cardiovascular system are becoming increasingly popular. The following represents the most promising technology in this growing field (Table 1).

Cardiac contractility modulation

A major limitation of CRT is the requirement for a prolonged QRS duration. It is estimated that only a quarter of heart failure patients have a prolonged QRS duration and, thus, are candidates for CRT [7]. In addition, as many as 18–52% of patients receiving CRT are considered nonresponders [8]. Cardiac contractility modulation (CCM) was introduced on the heels of CRT regulatory approvals as a means of improving left ventricular contractile function, independently of the QRS duration [9]. CCM signals are nonexcitatory signals that are applied during the absolute refractory period of the cardiac action potential (Fig. 1). CCM works by altering cardiomyocyte calcium handling [9]. In dog models of heart failure, treatment with CCM for 3 months led to a normalization of levels of phosphorylated phospholamban and increased expression of sarcoendoplasmic reticulum Ca transport ATPase (*SERCA2a*) and the ryanodine receptor [10]. The CCM currently works locally at the site of impulse transmission but can also impact, over time, remote areas; thus, it can have some effect on global reverse ventricular remodeling [10].

The FIX-HF-4 study was the first randomized controlled study to evaluate the safety and efficacy of the CCM system in human subjects. One hundred and sixty-four patients with an LVEF of less than 35% and NYHA class II or III symptoms received a CCM generator (OPTIMER system, Impulse Dynamics, Orangeburg, New York, USA) and were randomized to 12 weeks of treatment or sham [11]. The coprimary endpoints of peak oxygen consumption (VO_2) and quality of life assessed with the Minnesota Living with Heart Failure Questionnaire (MLWHFQ) both significantly improved with treatment. Importantly, there were no differences in the rate of adverse events between the active and sham arms [11].

FIX-HF-4 was underpowered to detect significant differences in mortality or heart failure admission rates. FIX-HF-5 attempted to shed additional light on the role of CCM by enrolling a sicker patient population [12]. In this multicenter study conducted across 50 centers in the United States, 428 patients with NYHA class III and IV symptoms and an ejection fraction (EF) less than 35% were randomized 1 : 1 to either the OPTIMIZER System and optimal medical therapy or optimal medical therapy alone. The primary efficacy endpoint of ventilatory anaerobic threshold at 6 months was not met, but there was a significant improvement in the secondary endpoints of peak VO_2, which improved by 0.65 ml/kg/min ($P = 0.024$), and MLWHFQ, which improved by 9.7 points ($P < 0.0001$). In a prespecified subgroup analysis, patients with an EF more than 25% and NYHA class III symptoms had a significant increase in ventilatory anaerobic threshold (0.64 ml/kg/min, $P = 0.03$), peak VO_2 (1.31 ml/kg/min, $P = 0.01$), MLWHFQ (10.8 points, $P = 0.03$) and NYHA status (−0.29, $P = 0.001$) at 6 months. Based on these observations, it is speculated that the secondary remodeling that occurs with CCM may be more efficacious in hearts with only modestly reduced ejection fractions, which have more contractile reserve than hearts with lower ejection fractions. The FIX-HF-5c study will further explore the effects of CCM in patients with only modestly reduced LVEF (25–45%), NYHA class III and IV heart failure and normal QRS duration [13].

Table 1. Electrical and neuromodulation devices in heart failure

Device	Mechanism of action	Cellular effects	Clinical effect	Ongoing trials
CCM  Reproduced with permission from Impulse Dynamics [13]	Nonexcitatory electrical signal delivered during the absolute refractory period	Improves cellular calcium handling ↑SERCA2a, NCX, phosphorylated phospholamban	Increases strength of left ventricular contraction; increases peak VO_2 and quality of life Effect greatest in patients with NYHA class III CHF and EF ≥25%	FIX-HF-5c RCT of CCM in patients with moderately reduced LVEF (25–45%), QRS <130 ms and NYHA class III or IV symptoms
VNS  Reproduced with permission from BioControl Medical [23]	Stimulate preganglionic parasympathetic neurons in the brainstem, which runs within the vagus nerve	Lengthens epicardial action potential duration and lowers vulnerability to VF. Decreases ventricular fibrosis and inflammation ↓TNF-α, IL-6 and CRP	Improves quality of life, NYHA class, 6MWT. May improve LVEF	INNOVATE-HF RCT VNS in patients with EF ≤40%, QRS <120 ms and NYHA class III symptoms
SCS	Stimulate afferent spinal nerve fibers leading to increased vagal tone and deceased sympathetic tone	Improves cellular work efficiency and alters nitric oxide handling, leading to redistribution of coronary flow	Improves NYHA class, peak VO_2, quality of life and LVEF. Improves cardiac work efficiency	DEFEAT-HF RCT of SCS in patients with EF ≤35%, NYHA class III symptoms and QRS <120 ms
Carotid sinus stimulation	Activate baroreceptors that in turn activate efferent vagal nerve fibers	Increases central vagal tone, normalizes β-adrenergic signaling and nitric oxide handling	Improves systolic and diastolic function; increases threshold for ventricular arrhythmias in dog models. Lowers blood pressure in human studies	HOPE4HF RCT of BAT in patients with symptomatic heart failure with elevated blood pressure and LVEF ≥40% XR-1 HF RCT of BAT in patients with EF ≤35% and NYHA class III symptoms

6MWT, six-minute walk test; BAT, baroreflex activation therapy; CCM, cardiac contractility modulation; CHF, congestive heart failure; CRP, C-reactive protein; DEFEAT-HF, determining the feasibility of spinal cord neuromodulation for the treatment of chronic heart failure; EF, ejection fraction; HOPE4HF, hope for heart failure; IL, interleukin; INNOVATE-HF, Increase of vagal tone in congestive heart failure; NCX, natrium calcium exchanger; RCT, randomized controlled trial; SCS, spinal cord stimulation; SERCA, sarcoendoplasmic reticulum Ca transport ATPase; TNF, tumor necrosis factor; VF, ventricular fibrillation; VNS, vagal nerve stimulation.

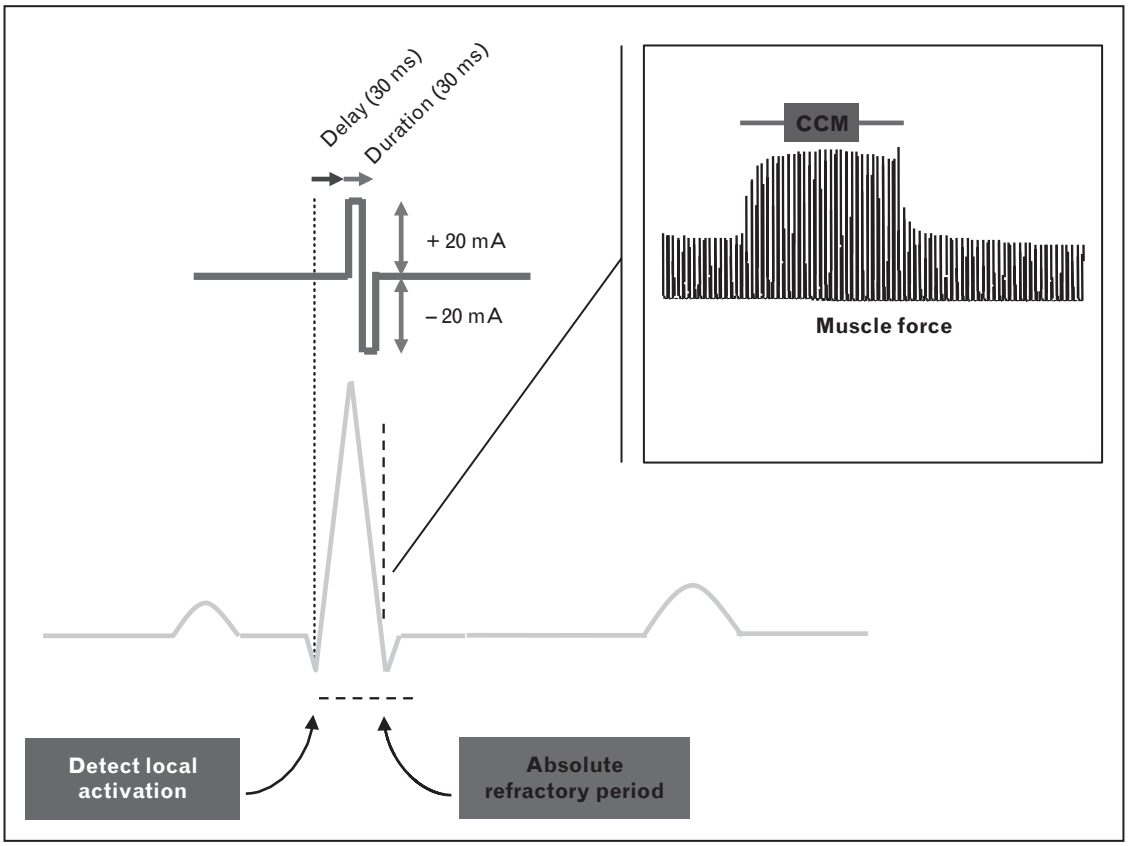


FIGURE 1. Timing and characteristics of CCM signal. CCM, cardiac contractility modulation.

Vagal nerve stimulation

Part of the body's adaptation to the chronic heart failure state is heightened sympathetic tone and reduced parasympathetic tone. Dog models suggest that there is impaired electrical transmission from the preganglionic to postganglionic parasympathetic neurons via the nicotinic acetylcholine receptors in animals with heart failure [14]. This then leads to a compensatory increase in cardiac muscarinic receptors [15]. The postganglionic nicotinic receptors are agonist dependent, and efferent transmission can be enhanced by chronic stimulation of the preganglionic fibers [16].

Cervical vagal nerve stimulation (VNS) has therefore become an intriguing target for heart failure management. VNS has anti-inflammatory and antifibrotic effects that can lead to ventricular reverse remodeling with improvements in ventricular dimensions and ejection fraction [17,18]. The Neural cardiac therapy for heart failure (NECTAR-HF) trial was the first randomized controlled trial of the safety and efficacy of VNS in heart failure. Ninety-six patients with NYHA class II or III heart failure with an LVEF 35% or less and left ventricular end diastolic dimension (LVEDD) at least 55 mm were enrolled in the study. All patients had the Precision system (Boston Scientific Corporation, St Paul, Minnesota, USA) implanted around their right vagus nerve and randomized 2 : 1 to treatment or control. There was no difference in the primary endpoint of change in left ventricular end-systolic diameter [19]. Patient blinding, however, was suboptimal in this study as patients were able to sense whether or not they were receiving stimulation [20].

The Autonomic Neural Regulation Therapy to Enhance Myocardial Function in Heart Failure (ANTHEM-HF) study evaluated the safety and efficacy of the Cyberonics VNS Therapy System (Cyberonics, Houston, Texas, USA). Sixty patients with NYHA class II or III heart failure with an LVEF 40% or less were implanted with the device. Device therapy led to an improvement in left ventricular end-systolic volume (−4.1 ml), left ventricular end-systolic diameter (−1.7 mm), LVEF (4.5%), heart rate variability (17 ms), 6-min walk test (56 m) and NYHA class in 77% of patients at 6 months when compared with baseline [21]. The ANTHEM-HF study demonstrated the feasibility of the Cyberonics system; however, a randomized controlled trial is still needed to further evaluate the efficacy of the device.

The Increase of vagal tone in congestive heart failure (INNOVATE-HF) trial is the largest trial to date investigating the role of VNS in heart failure. It is an event-driven, randomized controlled trial testing the CardioFit system (BioControl Medical, Yehud, Israel) that is currently ongoing. The trial hopes to enroll 650 patients on optimal medical therapy with NYHA class III heart failure with an LVEF 40% or less, QRS duration 120 ms or less and left ventricular end-diastolic diameter between 50 and 80 mm and randomize them in a 3 : 2 ratio for either treatment or control [22]. The study plans to follow patients for at least 1 year following enrollment and will be powered to detect any difference in the combined primary efficacy endpoint of all-cause mortality and heart failure hospitalizations [23]. A comparison of the different VNS devices currently under investigation is found in Table 2.

Spinal cord stimulation

Spinal cord stimulation (SCS) was first introduced in 1967 for the treatment of intractable pain [24]. Within cardiology, SCS is used for end-stage and refractory angina in patients with coronary artery disease and coronary syndrome X as well as severe symptoms of claudication in patients with peripheral arterial disease [25–27]. The peridural space is accessed at the L2-L3 level under fluoroscopy and the SCS leads are then advanced to either the lower cervical or the upper thoracic level of the spinal cord and positioned close to the dorsal horn fibers. The pulse generator is implanted in the subcutaneous space, in either the low back or the upper buttocks, and the leads are then tunneled in the subcutaneous space [24].

SCS applied to the low cervical (C7-C8) or upper thoracic (T1-T6) levels leads to reflex activation of sympathetic and parasympathetic nerves with a reequilibration in favor of the parasympathetic system [28,29]. Preclinical studies suggested that SCS decreases myocardial oxygen demand by improving cardiac work efficiency and lowering peripheral vascular resistance, while at the same time improving cardiac output [30]. In canine models, SCS reduces the rate of ventricular tachyarrhythmias, improves LVEF and lowers circulating B-type natriuretic peptide (BNP) levels [31].

The first randomized study of SCS in heart failure was recently reported by Torre-Amione *et al.* [32]. In this prospective, randomized, double-blind, crossover pilot study, nine patients with NYHA class III heart failure with an LVEF 30% or less and who had been hospitalized or received inotropic support in the past year underwent SCS system implant (St Jude Medical, Plano, Texas, USA) at the T1-T4 level. Patients were randomized to either 3 months with the device active (SCS-ACTIVE) or disabled (SCS-INACTIVE) followed by crossover to the other treatment. During SCS-ACTIVE phase 5, patients improved at least one NYHA class, and six patients had an improvement in their quality-of-life score. There was minimal overall change, however, in BNP or LVEF while receiving active therapy.

The safety and efficacy of SCS were also prospectively studied in the Spinal Cord Stimulation for Heart Failure (SCS HEART) study [33]. Seventeen men with NYHA class III heart failure and LVEF between 20 and 35% underwent SCS system implant (St Jude Medical) at the T1-T3 level. The devices were programmed to provide SCS continuously, and safety and efficacy were assessed at 6 months. Compared with baseline, SCS therapy led to improved NYHA class (3.0 vs. 2.1, $P = 0.002$), MLWHFQ (42 vs. 27, $P = 0.026$), peak VO_2 (14.6 ml/kg/kg vs. 16.5 ml/min/kg, $P = 0.013$), LVEF (25 vs. 37%, $P < 0.001$) and left ventricular end-systolic volume (174 vs. 140 ml, $P = 0.002$). The device was safely implanted in all patients without major complications, and there were no treatment-related major adverse events.

The results of the Determining the feasibility of spinal cord neuromodulation for the treatment of chronic heart failure (DEFEAT-HF) study, a randomized, single-blinded study, were recently reported at the 2014 American Heart Association's Scientific Sessions [34]. Patients with NYHA class III heart failure with an LVEF of 35% or less, QRS duration of 120 ms or less and LVEDD between 55 and 80 mm were implanted with PrimeADVANCED Neurostimulator (Medtronic Inc., Minneapolis, Minnesota,

Table 2. Comparison of vagal nerve stimulators

Device (manufacturer)	Pulse width (μs)	Frequency (Hz)	Active/inactive (duty cycle %)	Output (mean, SD) (mA)
CardioFit system (BioControl Medical) [22]	500	1–3	2 s/6 s (25)	4.1 ± 1.1
Precision System (Boston Scientific) [19]	300	20	10 s/ 50 s (16.7)	1.4 ± 0.8
Cyberonics VNS Therapy System (Cyberonics) [21]	250	10	14 s/66 s (17.5)	2.0 ± 0.6

VNS, vagal nerve stimulation.

USA). Patients were then randomized in a 3:2 fashion to either 6 months of therapy with SCS stimulation for 12 h a day (SCS On) or no therapy for 6 months (SCS Off). After 6 months, both the SCS On and SCS Off groups had their devices turned on and followed. With therapy, there was no difference in the primary endpoint of change in left ventricular end-systolic volume index or in the secondary endpoints of change in peak VO_2 and change in N-terminal prohormone of brain natriuretic peptide (NT-proBNP) [34]. Unfortunately, the trial was underpowered, and the role of SCS, if any, remains unclear.

Carotid sinus stimulation

As part of the maladaptive autonomic dysregulation of heart failure, patients with congestive heart failure undergo suppression of their baroreceptors [35]. Baroreceptors are embedded in the walls of arterial vessels and are preferentially concentrated in the carotid artery and the aortic arch [36]. In response to increases in arterial blood pressure, there is withdrawal of sympathetic tone and activation of efferent vagal nerve fibers [37]. Electrical stimulation of the baroreceptor fibers within the carotid sinus has been studied clinically in the treatment of resistant hypertension and is currently being studied in heart failure.

Preclinical studies with Baroreflex activation therapy (BAT) suggest that long-term electrical activation of the baroreflex can improve left ventricular systolic function and the rate of relaxation and can promote reverse ventricular remodeling in dog models [38]. In early clinical studies in humans, chronic BAT led to a reduction in healthcare utilization among a cohort of 11 patients receiving barostimulation therapy with the CVRx Neo System (CVRx, Minneapolis, Minnesota, USA) [39].

Two randomized controlled trials are currently underway investigating BAT in heart failure patients with both reduced and preserved ejection fraction, respectively. The hope for heart failure (HOPE4HF) trial is evaluating the safety and efficacy of the Rheos system (CVRx) in patients with an ejection fraction at least 40% [40]. The Barostim Neo system in the treatment of heart failure (XR1-HF) study recently completed enrollment of 140 patients with an LVEF 35% or less and NYHA class III symptoms. Patients were randomized 1:1 to either optimal medical therapy or optimal medical therapy and the CVRx Neo System (CVRx) [41].

MINIMALLY INVASIVE STRUCTURAL REMODELING

Several new devices aimed to circumvent the adaptive remodeling common in heart failure are currently in clinical investigation. The following highlights a few of the more promising technologies (Table 3).

Controlled interatrial shunts

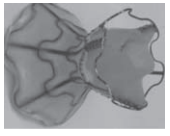
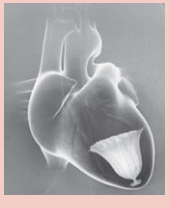
Elevated left ventricular end-diastolic and left atrial pressures are common in heart failure with both reduced and preserved ejection fraction. Patients with persistently elevated left-sided filling pressures develop symptoms of pulmonary edema and have frequent heart failure hospitalizations. Left heart decompression via either surgical or balloon atrial septostomy has been useful in select cases of acute decompensated heart failure [44,45].

The V-Wave device (V-Wave Ltd, Or Akiva, Israel) is a percutaneously implanted device that acts as a unidirectional left-to-right shunt in patients with left-sided heart failure. The device is implanted into the interatrial septum and is made of a nitinol frame covered with an expandable polytetrafluoroethylene membrane with a trileaflet porcine pericardial tissue valve sutured inside. The valve acts as a pressure-dependent, one-way valve that allows flow from the left atrium to the right atrium whenever the pressure differential exceeds 5 mmHg. Preclinical studies of the V-Wave device in a sheep model of heart failure showed that the device significantly lowered left atrial pressure without increasing right atrial pressure, with concomitant preservation of LVEF [46].

The feasibility of the V-Wave device was recently reported at EuroPCR 2014. Preliminary data from five patients showed continued safety of the device with a reduction in NT-proBNP and significant improvement in peak VO_2 (11.8 vs. 14.2 ml/kg/min, $P=0.034$) and 6-min walk time (284 vs. 326 m, $P=0.003$) compared with baseline [47]. The VW-SP-1 study is a prospective, open label, single-arm study in patients with LVEF between 15 and 40% and NYHA class III or IV heart failure, which is currently enrolling to study the safety and efficacy of the V-Wave device [48].

Similarly, the feasibility of the InterAtrial Shunt Device (IASD) system (DC Devices Inc, Cambridge, Massachusetts, USA) in 11 patients with heart failure with preserved ejection fraction was recently reported [49]. Patients with an EF more than 45% with a baseline pulmonary capillary wedge pressure more than 15 mmHg at rest or more than 25 mmHg with exercise with persistent NYHA class III or IV heart failure were percutaneously implanted with the IASD system. The device was safely implanted in all patients with an average reduction in the pulmonary capillary wedge pressure by 5.5 mmHg ($P=0.005$) [50]. The REDUCE LAP-HF trial is an ongoing, single-arm, open label study to evaluate

Table 3. Structural remodeling devices in heart failure

	Device	Mechanism of action	Procedural details	Clinical effect	Ongoing trials
Controlled interatrial shunts	 Reproduced with permission from [42]	Decompresses left ventricle and left atrium via a one-way left to right shunt	Transcatheter approach	Improves left-sided filling pressures, quality of life, peak VO_2 and 6MWT	VW-SP-1 Non-RCT of the V-Wave shunt in patients with an EF between 15 and 40% and NYHA class III or IV symptoms REDUCE LAP-HF Non-RCT of the IASD system II in patients with an EF >40% and NYHA class II–IV symptoms
Ventricular restoration	 Reproduced with permission from [43]	Mechanically isolates scarred and dysfunctional myocardium leading to improved ventricular shape and mechanics	Transcatheter approach (Parachute device and Revivent TC) Surgical approach (Revivent)	Improves NYHA class and quality of life; reduces left ventricular systolic and diastolic volumes	PARACHUTE IV RCT of the Parachute device in patients with an EF between 15 and 35%, prior anterior MI with scar and NYHA class III or IV symptoms CONFIGURE-HF Non-RCT of the Revivent system in patients with an EF between 15 and 45% and prior anterior MI with scar

6MWT, six-minute walk test; CONFIGURE-HF, prospective study of the BioVentrix PliCath HF System for the treatment of ischemic cardiomyopathy; IASD, InterAtrial Shunt Device; MI, myocardial infarction; RCT, randomized controlled trial; VW-SP-1, the V-wave shunt: First in man safety and feasibility study.

the safety and efficacy of the IASD System II (DC Devices Inc.) to reduce elevated left atrial pressure in patients with an LVEF of more than 40% and NYHA class II, III or IV heart failure [51].

Ventricular restoration

Left ventricular remodeling in heart failure leads to progressive left ventricular chamber dilation and myocardial fibrosis. Surgical ventricular reconstruction, as a means to alter left ventricular volume, shape and physiology, was studied in earnest as a means to improve ventricular function and improve neurohormonal balance [52]. Optimism for surgical ventricular reconstruction waned following the surgical treatment of ischemic heart failure (STICH) study, which failed to show a reduction in the composite endpoint of death and hospitalization from cardiac causes [53]. However, the study was criticized for several limitations, including lack of consistent reduction of left ventricular volume and inclusion of inappropriate patients.

The Parachute device (CardioKinetix Inc., Menlo Park, California, USA) is a percutaneous ventricular partitioning device that separates the left ventricular apex from the main part of the chamber. The Parachute device is a partitioning membrane shaped like an umbrella with 16 struts made of a self-expanding nitinol frame covered in an polytetrafluoroethylene membrane. The device forms an occlusive barrier that seals off the apical portion of the ventricle. The division is intended to reduce myocardial stress in the dynamic chamber [54]. Ovine models in which the Parachute device was tested showed a reduction in left ventricular size and improved left ventricular systolic function [55].

The feasibility of the device was tested in the PARACHUTE trial, which was a prospective, single-arm study of 39 patients with prior anterior myocardial infarction with anteroapical akinesis or dyskinesis with LVEF 40% or less and NYHA class II to IV heart failure. Ninety-one percent of patients underwent successful implantation. At 12 months after device implantation, there was a significant improvement in NYHA class (2.5 vs. 1.3, $P < 0.001$) and quality of life assessed by the MLWHFQ (38.6 vs. 28.4, $P < 0.02$) [54]. Three-year follow-up in 23 of the original participants showed a maintenance of the improved NYHA class in 85% of the patients [56].

PARACHUTE III is an ongoing multinational, observational study of postmarked European patients who have already received the Parachute device. Preliminary results of 12-month clinical data from 111 consecutive patients presented at American College of Cardiology 2014 revealed a high procedural success rate of 96%, sustained reduction in left ventricular volumes, improvement in LVEF (28.4 vs. 30.4%, $P < 0.05$) and improvement in 6-min walk time performance (365 vs. 390 m, $P < 0.05$) [57]. The efficacy and long-term safety of the Parachute device will be thoroughly studied in the PARACHUTE IV, the pivotal randomized control trial [43].

Another approach to ventricular reconstruction is offered by the Revivent Myocardial Anchoring System (BioVentrix Inc., San Ramon, California, USA). This system is composed of articulating, polyester-covered titanium anchors mounted on a polyethylene-ether-ether-ketone tether. The system is delivered either via a minimally invasive surgery or percutaneously through an endovascular approach, and the anchors are then deployed through the left ventricular free wall and interventricular septum around an area of anterior myocardial scar. A unidirectional anchor then allows apposition of the left ventricular free wall at the scar perimeter to the septum, effectively isolating the scarred area from the rest of the ventricle [58]. When delivered surgically, the Revivent system led to a sustained reduction of left ventricular end-systolic volume index and left ventricular end-diastolic volume index at 6 and 12 months after surgery [58]. The CONFIGURE-HF study is a prospective, single-arm study currently studying the safety and efficacy of the minimally invasive surgical deployment system [59].

CONCLUSION

In summary, several novel devices targeting electrical, neurohormonal and structural remodeling of the heart are currently being studied in patients with heart failure. Although several of the aforementioned devices are only in the early stages of clinical development, it is anticipated that some of these technologies will ultimately be among the growing armamentarium for the treatment of advanced and end-stage heart failure.

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Conflicts of interest

D.B. is an employee of HeartWare International. He serves on the advisory boards of DC Devices, Sorin, Sensible Medical and Cardiac Implants. He receives an educational grant from Abiomed. J.G. has no conflict of interest.

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