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Implantable devices for heart failure monitoring: the CardioMEMS™ system

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Several devices have been developed for heart failure (HF) treatment and monitoring. Among device-based monitoring tools, CardioMEMS™ has received growing research attention. This document reflects the key points of an ESC consensus meeting on implantable devices for monitoring in HF, with a particular focus on CardioMEMS™.

Introduction

Heart failure (HF) is a complex disorder with haemodynamic, neurohormonal, metabolic, functional and electrical aspects to be considered, along with the impact non-cardiovascular co-morbidities. In historical times, the patient attended a physician for evaluation and the physician would examine the patient and made special measurements to determine the state of the patient sand what treatments were needed. For HF, this was almost entirely a haemodynamic or congestion assessment, as the only effective treatments before the 1980s were diuretics or digoxin. Blood pressure, heart rate, jugular venous pressure and auscultation of the lungs were all ways the physician would assess the patient's haemodynamic status, supplemented by heart rhythm assessment. Later echocardiography gave another window into haemodynamic assessment offering measures of left ventricular systolic and diastolic functions and even indirectly filling pressures and pulmonary artery pressures (PAPs). Doppler techniques could be used to estimate cardiac output. At infrequent intervals, some invasive haemodynamic measurements could be performed at cardiac catheterization to obtain direct haemodynamic measures, and the future management plans of the patient would be significantly modified after such a haemodynamic assessment; such as a transplant eligibility assessment.

With the advent of ACE inhibitors, ARB's, beta-blockers and MRA's modifying disease outcomes without predominantly affecting haemodynamics, this "haemodynamic" model of HF fell somewhat out of favour, and physicians began to make treatment plans based on guideline directed medical therapy recommendations, themselves largely based on applying the results of trial results, that did not involve haemodynamic monitoring of HF patients. Haemodynamic assessment thus became less frequently used to guide most treatment decisions. The management of HF patients at home became more driven by symptoms and nurse evaluation or by simple monitoring techniques such as daily weight measurements to adjust diuretic doses.

The development of miniature implantable devices which could measure haemodynamic variables and transmit them to a monitor outside the body changed this paradigm and offered. For the first time, a possibility for a physician to obtain more frequent haemodynamic evaluation of HF patients, and the opportunity to take these data into account in their management decisions. The question that arose were how would the doctor make use of these data, and would this make a difference to the treatments prescribed and via that mechanism would it affect long-term patient outcomes.

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At the time of the 2016 ESC Heart Failure Guidelines,[1] the only recommendations regarding the use of implantable haemodynamic monitoring was that of PAP monitoring using the CardioMEMS™ system, in which it was advised that the use of the CardioMEMS™ system may be considered in symptomatic patients with HF with previous HF hospitalization in order to reduce the risk of recurrent HF hospitalization (with a class IIb recommendation), and multiparameter monitoring based on implanted ICD's with this capacity (the "IN-TIME approach"[2]), in which it was advised that this may be considered in symptomatic patients with HFrEF (LVEF $\leq$35%) in order to improve clinical outcomes, also with a class IIb recommendation. The CHAMPION trial[3,4] had shown the utility of PAP-guided HF monitoring with the CardioMEMS™ system in high-risk HF patients and advanced HF. The CHAMPION trial included 550 patients implanted with a permanent MEMS-based pressure sensor in the pulmonary artery (PA) and the primary endpoint of HF-related hospitalizations at 6 months was significantly reduced [hazard ratio (HR) 0.70, 95% confidence interval (CI): 0.60–0.84, $P < 0.0001$] and during the entire follow-up, the treatment group had a 39% reduction in HF-related hospitalization compared with the control group (153 vs. 253, HR 0.64, 95% CI: 0.55–0.75; $P < 0.0001$). A subsequent sub-study in 245 Medicare-eligible subjects showed medications were changed more often in the treatment group compared with the control group and this was associated with an overall rate of HF hospitalizations that was 49% lower in the treatment group (60 HF hospitalizations, 0.34 events/patient year) compared with control (117 HF hospitalizations, 0.67 events/patient year; HR 0.51, 95% CI: 0.37–0.70; $P < 0.0001$) along with a 58% reduction in all-cause 30 day readmissions.[5] It appears also to be effective in HFpEF.[6] However, the implementation of this device in routine practice remains challenging, because of the cost[7] and the need for an infrastructure to be able to receive the daily measurements and to respond to them in a timely fashion, not least the issue of whose responsibility is to capture and respond to these new data and how that effort is to be funded within the local health care system. For example, in many European Countries, there is no reimbursement for the workload involved in monitoring patients with implantable devices.

An alternative approach, that of an implantable right ventricular (RV) pressure monitoring failed to reduce HF hospitalizations significantly in a smaller trial (COMPASS-HF) compared with CHAMPION.[8] The IN-TIME trial studied HF patients with a recent dual-chamber ICD or CRT-D implantation. After a 1 month run-in phase, patients were randomly assigned (1:1) to either automatic, daily, implant-based, multiparameter telemonitoring in addition to standard care or standard care without telemonitoring. The primary outcome (death or, HF hospitalization, or change in either NYHA class or patient global self-assessment) was significantly improved, 63 (18.9%) of 333 vs. 90 (27.2%) of 331 in the control group ($P = 0.013$, odds ratio 0.63, 95% CI: 0.43–0.90) along with 10 vs. 27 deaths during follow-up. The basis of these results appears to be that blood volume expansion, and incipient pulmonary oedema may start many days before classical decompensation symptoms or even weight changes occur, and thus monitoring physiologic signals from implanted devices may provide earlier warning of impending decompensation episodes, facilitating diuretic or haemodynamically acting drug interventions.[9] An alternative approach is that of implantable impedance monitors that can detect fluid volumes in the thorax and lung. In the Fluid Accumulation Status Trial (FAST) study, 156 HF patients had their ICD or CRT-D devices modified to record daily intrathoracic impedance. In these patients, 40 HF events of a total of 65 were detected by impedance but not by body weight changes, whereas only five were detected by weight changes but not by impedance measure.[10] The SENSE-HF trial, however, using a similar approach showed in 501 HF patients showed this had low sensitivity (20.7%) and positive predictive accuracy (4.7%) for detecting HF hospitalizations.[11] Also the OptiLink HF (Optimization of Heart Failure Management using OptiVol™ Fluid Status Monitoring and CareLink™) study of whether automated fluid status (implantable impedance monitor) alert notification via telemedicine improves outcome in 1002 HF patients was neutral in its primary Endpoint (CV death or CV hospitalization) with 45.0% active vs. 48.1% in the control arm [HR, 0.87; 95% CI: 0.72–1.04; $P = 0.13$] 59 (11.7%) vs. 63 (12.7%) deaths (HR, 0.89; 95% CI: 0.62–1.28; $P = 0.52$). It was noteworthy that 24% of alerts were not transmitted and only 30% were followed by a medical intervention, indicating the need for the health care system to be able and ready to act on the data transmitted. The EVOLVO study showed in 200 HF patients that audible alarms at home in patients with ICD's lead to more hospital or clinic visits compared with patients with the alarm inactivated and the notification being sent wirelessly to the hospital/clinic instead[12] with 75 emergency department/urgent in-office visits for HF, arrhythmias or ICD-related events in the remote arm vs. 117 in the standard arm (0.59 vs. 0.93 events per year; incident rate ratio [IRR], 0.65; 95% CI: 0.49–0.88; $P = 0.005$). The much larger REM-HF study in 1650 HF patients using multiple manufacturers' implantable devices, however, failed to a show a reduction in the combined endpoint of death or CV hospitalization [349 patients (42.4%) in the RM group and in 347 patients (40.8%) in the UC group (HR 1.01; 95% CI: 0.87–1.18; $P = 0.87$)]. The devices were CRT, CRT-P or CRT-D or ICD and the trial involved weekly data downloads from the patients' devices with simultaneous review by remote monitors.

Other approaches that have been tested include implantable left atrial pressure monitoring, but one study was stopped early due to procedure-related complications.[13] Another trial (REDUCE-HF) with an implantable haemodynamic monitor ceased premature due to haemodynamic RV pressure lead problems.[14] Ultimately any such device needs to show it can improve outcomes, which will require specifically designed trials.[15]

The management of cardiac arrhythmia and advanced HF syndromes is particularly challenging. For these reasons, the use of cardiac implantable electronic devices is pivotal in HF management and monitoring. Main applications of device therapy in HF are cardiac resynchronization therapy and treatment of ventricular tachycardia or fibrillation for prevention of sudden cardiac death.[16] Beyond

treatment, devices are used in HF monitoring although their implementation is still challenging.

For this reason, a multidisciplinary panel of leading international experts has been organized by the ESC to discuss the issues related to physiological monitoring of HF using implantable devices. The key points of the meeting are reflected in this document.

CardioMEMS™

Many devices are currently approved for clinical use or are under investigational use for the monitoring of HF.[17] Device-based monitoring tools are classified into PAP monitor, RV monitor (the Chronicle™; Medtronic Inc., Minneapolis, MN, USA), left atrial pressure monitor (HeartPOD™), intrathoracic impedance monitor [The Medtronic Inc. OptiVol Fluid Status Monitor and the St. Jude Medical (SJM) CorVue™ Congestion Monitor] and Lung Fluid monitor (ReDS; Sensible Medical Innovations Ltd, Netanya, Israel).

So far, the only FDA-approved remote monitoring system for patients with HF is Cardio-Microelectro-mechanical system (CardioMEMS™; Abbott, Sylmar, CA, USA). This is an implantable PAP monitoring device that allows a direct monitoring of the PAP via a sensor implanted in the PA.[2] The sensor monitors changes in the PAPs and communicates via wireless to an external analyser. This information is then uploaded to a web-based interface from which healthcare providers can track the results and manage patients.[1,2]

The ongoing prospective, observational MEMS-HF study[18] will evaluate the safety and feasibility of CardioMEMS™ system in Europe, shedding new light on the utility of haemodynamic-guided HF management in improving clinical outcomes.

Future directions

Detailed recommendations for standardized, structured post-implant HF care, and for the management of ambulatory PAP trends are needed.

Reductions in HF-related hospitalizations are achievable by novel device-based telemonitoring strategies, that should be feasible at little extra cost.

Such a novel diagnostic adjunct should be incorporated into existing HF disease management strategies. Patients should be monitored using individualized PAP thresholds to trigger medication adjustments during follow-up by specifically trained nurses in a multidisciplinary HF management for all patients with advanced HF. Thus, beyond reimbursement, in order to improve the implementation of device therapy in routine clinical practice, training/education of specialized team is required.

Conflicts of interest: none declared.

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