Available online at www.sciencedirect.com

SciVerse ScienceDirect

Journal of Electrocardiology 44 (2011) 611 – 615

JOURNAL OF Electrocardiology

www.jecgonline.com

Evolutionary innovations in cardiac pacing☆

Alan Cheng, MD,* Larisa G. Tereshchenko, MD, PhD

Department of Medicine, Division of Cardiology, Section of Cardiac Electrophysiology, Johns Hopkins Medical Institutes, Baltimore, MD, USA

Received 10 April 2011

Abstract Cardiac pacing has played a significant role in mitigating morbidity and mortality associated with bradyarrhythmias. Throughout the years, advances made in battery reliability, lead performance, and device portability have rapidly expanded the use of cardiac pacemakers in many different disease states. Despite the benefits, there has been growing awareness of the potential deleterious effects of long-term artificial electrical stimulation including the development of ventricular dyssynchrony and atrial fibrillation. Given their association with an increased risk for heart failure and possibly death, several advances aimed at minimizing them have been made in recent years including changes in atrioventricular pacing algorithms, novel pacing mode modifications, and better identification of hemodynamically optimal pacing sites. This article reviews the advances made and the future direction of innovations in cardiac pacing.

Keywords: Pacemaker; Heart failure; Atrial fibrillation; Innovations

Introduction

Since the early days[1,2] of portable cardiac pacing in the 1950s, significant advancements in pacemaker technology have allowed for improved performance and specialized pacing capabilities such that the therapy was applied not only in individuals with high risk for bradyarrhythmic cardiac arrest but also in those with less severe risk profiles. In fact, current guidelines for pacemaker implantation have evolved to include individuals with any evidence of symptomatic bradycardia (typically secondary to sinus node dysfunction).[3] This has led to an ever-growing number of individuals with implantable devices and the realization that permanent cardiac pacing is the only effective treatment against this condition. With growing experience, it was also realized that cardiac pacing had potentially deleterious effects. Hence, great interest developed in findings ways of improving this therapy. Over the years, these innovations have brought forth enhancements in safety and reliability as well as strategies against these potentially deleterious effects. We review the major advancements made in improving the safety profile of pacemakers as well as discuss directions for future innovations in this field.

Early unmet needs in pacing: non–nocere primum

Looking back on the history of innovations in cardiac pacing, one realizes that the greatest achievements have often been those designed to address the greatest unmet needs. The more significant and urgent the need, the greater impact the discovery had on common daily practice. It is with little doubt that one of the most pressing issues realized early on was the potential deleterious effects of cardiac pacing. Because the first renditions of the pacemaker focused on stimulating the ventricle, early retrospective observations suggested that patient outcomes differed. Individuals with sinus node dysfunction treated with atrial pacing fared better than those treated with ventricular pacing.[4] These findings led to randomized trials between atrial-only–based pacing (AAI) and ventricular-only–based pacing (VVI) that eventually demonstrated reductions in atrial fibrillation and thromboembolism when patients were treated with AAI.[5] Although total mortality and heart failure were not different between the 2 groups initially, patients treated with AAI pacing eventually demonstrated significant reductions in total mortality and heart failure after 8 years of follow-up.[6] There is biological plausibility for these observations,[7,8] but left unanswered was whether these differences were secondary to preservation of atrioventricular synchrony, avoidance of ventricular pacing, or both. Early adoption of pacing systems using only an atrial lead was met with great resistance out of concern for the development of atrioventricular heart block (which is currently estimated at 0.6% per

☆ Financial Support: None.

* Corresponding author. 600 N. Wolfe St, Carnegie 568, Baltimore, MD 21287, USA.

E-mail address: alcheng@jhmi.edu

0022-0736/$ – see front matter © 2011 Elsevier Inc. All rights reserved.
doi:10.1016/j.jelectrocard.2011.07.021

year). Hence, dual-chamber pacemakers (DDD) became the standard of care. This provided an opportunity to evaluate whether ventricular pacing was the reason for the deleterious differences seen in early studies.

With atrioventricular synchrony restored with dual-chamber systems, subsequent studies on mortality, heart failure, and atrial fibrillation demonstrated mixed results when compared with VVI pacing strategies. The Canadian Trial of Physiologic Pacing randomized 2568 to physiologic pacing (AAI or DDD) or VVI pacing and found that after an average follow-up of 3 years, physiologically paced patients demonstrated reductions in atrial fibrillation (as compared with VVI patients) but no difference in the combined end point of stroke or cardiovascular death.[9] These findings were similar to those from the Mode Selection Trial in Sinus-Node Dysfunction where individuals were randomized to DDD or VVI pacing.[10] Less atrial fibrillation was seen in patients with DDD pacing with a hazard ratio of developing atrial fibrillation of 0.79 (confidence interval, 0.66-0.94). Although the primary end point of death or nonfatal stroke and the secondary end point of heart failure were not different between the 2 groups, the Mode Selection Trial in Sinus-Node Dysfunction investigators reported a subsequent analysis addressing the issue of whether the degree of ventricular pacing correlated with the development of atrial fibrillation and heart failure.[11] The relative risk for atrial fibrillation increased directly with the amount of cumulative ventricular pacing (Fig. 1). The incidence of heart failure similarly increased with greater degrees of cumulative ventricular pacing. These observations, coupled with reports from other studies,[12,13] led to 3 conclusions regarding the relationship of right ventricular pacing and heart failure: (1) a direct increase for heart failure occurs with increasing cumulative ventricular pacing such that there is a 54% increased risk for heart failure for every 10% increase in pacing; (2) individuals at greatest risk for development of right ventricular pacing–induced heart failure included those with structural heart disease (left ventricular ejection fraction <41%); and (3) the wider the paced QRS complex, the greater the risk for heart failure hospitalization over a 2-year period. This has led many to exercise the "Rule of 40" (increased risk for heart failure for those with a preexisting reduction of left ventricular ejection fraction <41% and those expecting to ventricularly pace >40% of the time). Minimizing ventricular pacing, therefore, became one of the most important unmet needs that faced cardiac pacing.

Historical innovations in cardiac pacing: minimizing ventricular pacing

Although the most reliable strategy to reduce ventricular pacing is to avoid implanting a ventricular lead, the

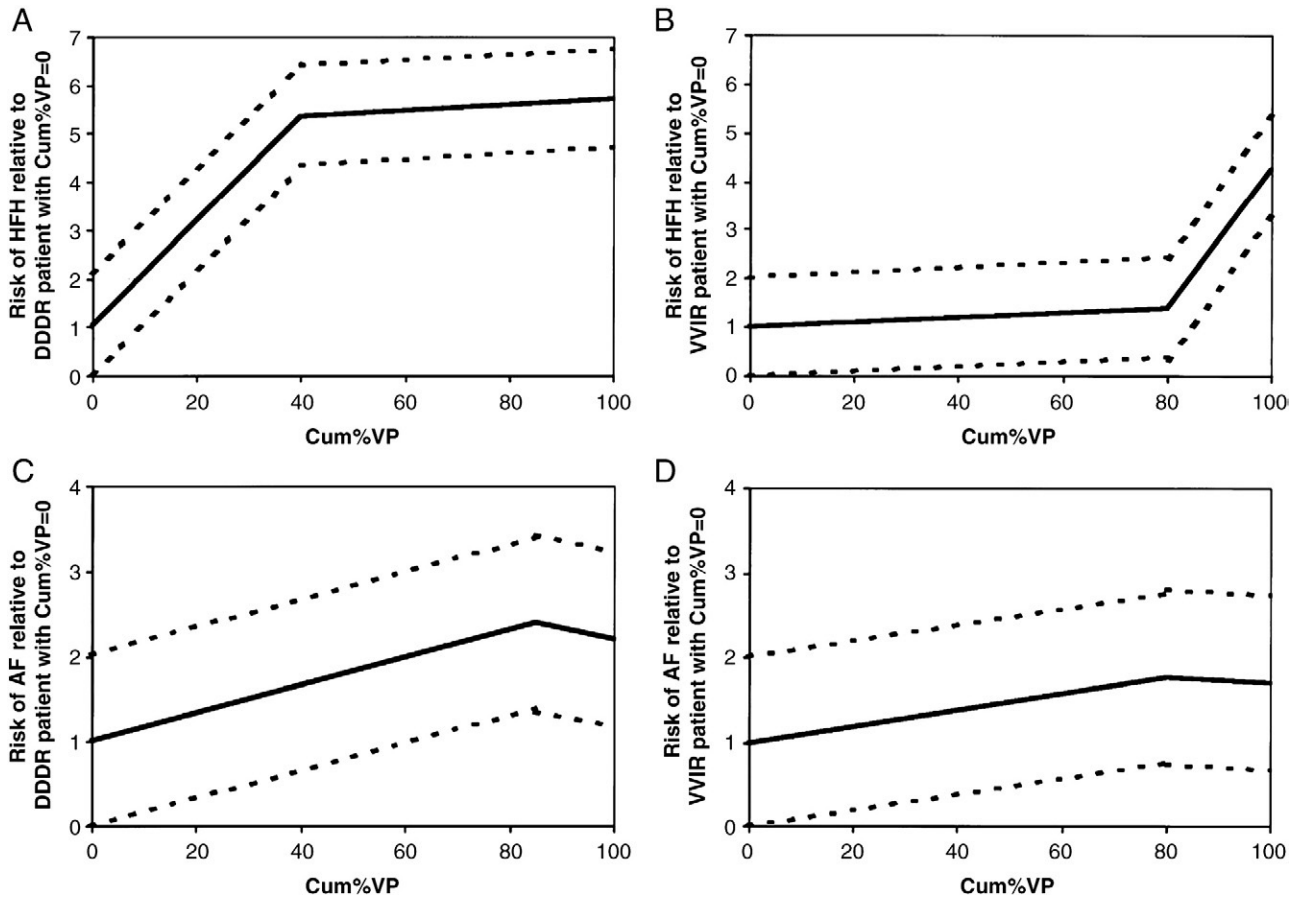

Fig. 1. Cox models with linear spline functions for the risk of heart failure hospitalization (A and B) and atrial fibrillation (C and D) as a function of cumulative ventricular pacing relative to patients pacing in DDD and VVIR.