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Basic Principles of Hemodynamics in Pacing 133

Alejandra A. Miyazawa, Darrel P. Francis, and Zachary I. Whinnett

Pacing therapy aims to improve overall cardiac function by normalizing cardiac electrical activation. Although hemodynamic measurements allow the impact of cardiac pacing on cardiac function to be quantified, the protocol is crucial to minimize the effect of noise and achieve greater precision. Multiple steps can be undertaken to optimize accuracy of hemodynamic measurements. These include comparing with a reference state, using an average of a set number of beats, making repeated measurements, ensuring all beats are included, and pacing at faster heart rates. These measurements can aid comparison between different pacing modalities and guide optimal programming.

His Bundle Pacing: My Experience, Tricks, and Tips 141

Francesco Zanon, Lina Marcantoni, Marco Centioni, Gianni Pastore, and Enrico Baracca

His Bundle Pacing (HBP) is a form of physiologic pacing achieved through implantation of a pacing electrode into the His bundle. HBP began 20 years ago without any dedicated tools. As specific tools became available HBP quickly spread and proved to be a viable alternative to traditional right ventricle pacing. HBP is reliable and effective in preserving the physiologic ventricular synchrony with clinical benefits particularly evident when a high percentage of pacing is required. Unipolar signals from the lead tip guide the implant. 3D electroanatomical mapping could further assist the procedure.

Physiologic Differentiation Between Selective His Bundle, Nonselective His Bundle and Septal Pacing 151

Marek Jastrzębski

His bundle (HB) pacing is an increasingly popular method of physiologic ventricular pacing. The electrocardiographic hallmark of physiologic pacing is the preservation or restoration of physiologic activation times in the left ventricle—a principle of paramount diagnostic importance. The current review focuses on the differentiation between 3 possible capture types when the pacing lead is placed in the HB region: selective HB capture when only HB is activated, nonselective HB capture when there is simultaneous activation of the adjacent right ventricular septal (RVS)

myocardium, and selective RVS capture when HB is not activated at all but only septal myocardium.

Left Bundle Branch Pacing: How I Do It? **165**

Lan Su, Kenneth A. Ellenbogen, and Weijian Huang

Since the first case of left bundle branch pacing (LBBP) achieved via the transventricular septal approach in 2017, LBBP has rapidly evolved into clinical practice with a high success rate and satisfactory pacing/sensing parameters compared with His bundle pacing (HBP). In this article, we review the criteria of LBB capture, standardized testing methods of LBBP. We focus on the determination of the initial lead entry site in the right side of the interventricular septum for LBBP, deep fixation of the lead tip into the left ventricular septal sub-endocardium, avoidance of lead septal perforation and solutions to challenging cases.

Physiology of Left Ventricular Septal Pacing and Left Bundle Branch Pacing **181**

Jesse Rijks, Justin Luermans, Luuk Heckman, Antonius M.W. van Stipdonk, Frits Prinzen, Joost Lumens, and Kevin Vernooy

Following the recognition of the adverse effects of right ventricular pacing, alternative permanent pacing strategies aiming to maintain a synchronous ventricular contraction have been sought. The quest for the optimal pacing site has recently led to several promising and rapidly emerging new pacing strategies, such as left ventricular septal pacing and left bundle branch pacing. In both animal and human studies, these pacing strategies seem to maintain electrical and mechanical activation of the left ventricle to a (near)physiologic level. However, more studies on the long-term effects of both strategies are needed.

Evaluation of Criteria for Left Bundle Branch Capture **191**

Shunmuga Sundaram Ponnusamy and Pugazhendhi Vijayaraman

Left bundle branch pacing (LBBP) provides electrical and mechanical synchrony at low and stable pacing output and effectively corrects distal conduction system disease. The criteria for differentiating LBBP from LV septal pacing has not been validated in large trials. There are several electrocardiography-based and intracardiac electrogram-based criteria to confirm LBB capture. In this section, the authors review these criteria and their overall accuracy.

What Intracardiac Tracings Have Taught Us About Left Bundle Branch Block **203**

Jeremy S. Treger and Gaurav A. Upadhyay

Current electrocardiogram (ECG) criteria for left bundle branch block (LBBB) are largely based on early work in animal models or on mathematical models of cardiac activation. The resulting criteria have modest specificity, and up to one-third of patients who meet current ECG criteria for LBBB may have intact conduction through their His-Purkinje systems. Intracardiac tracings offer the ability to accurately discriminate between LBBB and other causes of delayed activation, which may facilitate the development of more accurate ECG criteria. Assessing these distinctions are particularly salient to applications for conduction system pacing.

What Body Surface Mapping Has Taught Us About Ventricular Conduction Disease Implications for Cardiac Resynchronization Therapy and His Bundle Pacing 213

Marc Strik, Sylvain Ploux, and Pierre Bordachar

The degree and pattern of conduction disease seem determinant when assessing potential cardiac resynchronization therapy (CRT) candidates. In the present review, the authors discuss the available noninvasive techniques that can be used to acquire ventricular activation time maps. They describe what body surface mapping has taught us about left bundle branch block, right bundle branch block, intraventricular conduction delay, and right ventricular pacing and discuss the ability of derived parameters of electrical dyssynchrony to predict long-term clinical response to CRT or His bundle pacing.

Pacing Optimized by Left Ventricular dP/dt_{max} 223

Mark K. Elliott, Vishal S. Mehta, and Christopher A. Rinaldi

Left ventricular (LV) dP/dt_{max} provides a sensitive measure of the acute hemodynamic response to cardiac resynchronization therapy (CRT) and can predict reverse remodeling on echocardiography. Its use to guide LV lead placement has been shown to improve outcomes in a multicenter randomized trial. Given the invasive protocol required for measurement, it is unlikely to be universally beneficial for patients undergoing CRT but may be useful for patients who do not respond to conventional CRT, or in those who have borderline indications or risk factors for nonresponse. In such cases, LV dP/dt_{max} may help guide LV lead placement, optimize device programming, and select the best alternative method of delivering CRT, such endocardial LV pacing or conduction system pacing.

Role of Electrical Delay in Cardiac Resynchronization Therapy Response 233

Zain S. Gowani, Brett Tomashitis, Chau N. Vo, Michael E. Field, and Michael R. Gold

Traditionally, left ventricular (LV) lead position was guided by anatomic criteria of pacing from the lateral wall of the LV. However, large trials showed little effect of LV lead position on outcomes, other than noting worse outcomes with apical positions. Given the poor correlation of cardiac resynchronization therapy (CRT) outcomes with anatomically guided LV lead placement, focus shifted toward more physiologic predictors such as targeting the areas of delayed mechanical and electrical activation. Measures of left ventricular delay and interventricular delay are strong predictors of CRT response.

Programming Algorithms for Cardiac Resynchronization Therapy 243

Niraj Varma

Current cardiac resynchronization therapy (CRT) implant guidelines emphasize the presence of electrical dyssynchrony (left bundle branch block (LBBB) and QRS > 150 ms) yet have modest predictive value for response and have not reduced the 30% nonresponse rate. Optimized programming to optimize CRT delivery has promised much but to date has largely been ineffective. What is missing is the understanding of LV paced effects (which are unpredictable) and optimal paced AV interval (that can be conserved during physiologic variations) that then can be incorporated into an individualized programming prescription. Automatic device-based algorithms that deliver electrical optimization and maintain this during ambulatory fluctuations in AV interval are discussed.

Multisite Left Ventricular Pacing in Cardiac Resynchronization Therapy 253

Sandeep K. Jain and Samir Saba

Cardiac resynchronization therapy (CRT) is an established treatment of patients with heart failure with reduced ejection fraction and prolonged ventricular depolarization on surface electrocardiogram. Although patients' characteristics, such as their type of cardiomyopathy and the morphology and width of their baseline QRS complex, have been associated with CRT response, these features are not modifiable. Left ventricular multisite pacing has been proposed and tested as a tool to improve response to CRT and positively impact patient outcomes. This article reviews the published literature on left ventricular multisite pacing, with focus on the results of recently presented or published clinical trials.

Left Ventricular Endocardial Pacing: Update and State of the Art 263

Pierre Bordachar, Marc Strik, and Sylvain Ploux

Initially, left ventricular (LV) endocardial pacing was performed as a bailout procedure after unsuccessful transvenous cardiac resynchronization therapy implantation in the presence of surgical contraindications. Additional possible advantages of endocardial LV pacing are a more physiologic activation, being less arrhythmogenic, more effective on the hemodynamic level, with better thresholds, and without the risk of phrenic stimulation. Different techniques have been proposed to stimulate the LV endocardium in humans, with feasibility and safety studies involving limited numbers of patients. In this review, we will describe the different techniques proposed to allow LV endocardial pacing, the results observed, and then we will discuss the reasons why LV endocardial pacing seems to be out of fashion today and what are the possible perspectives for development.

Case Studies of Cardiac Resynchronization Therapy "Nonresponders" 273

John Rickard

Video content accompanies this article at http://www.cardiacep.theclinics.com.

Outcomes following cardiac resynchronization therapy (CRT) vary widely, with some patients experiencing normalization of left ventricular function to some who seem to be harmed by biventricular pacing. The care of CRT patients postoperatively is complex and requires input from physicians specializing in electrophysiology, heart failure, and often cardiac imaging. In this section, cases of apparent CRT suboptimal response from a dedicated CRT optimization clinic are presented.

What Have We Learned in the Last 20 Years About CRT Non-Responders? 283

Peregrine G. Green, Neil Herring, and Timothy R. Betts

Although cardiac resynchronization therapy (CRT) has become well established in the treatment of heart failure, the management of patients who do not respond after CRT remains a key challenge. This review will summarize what we have learned about non-responders over the last 20 years and discuss methods for optimizing response, including the introduction of novel therapies.

Conduction System Pacing for Cardiac Resynchronization Therapy 297

Bengt Herweg, Allan Welter-Frost, David R. Wilson II, and Pugazhendhi Vijayaraman

Although conventional biventricular pacing has been shown to benefit patients with heart failure and conduction system disease, there are limitations to its therapeutic

success, resulting in widely variable clinical response. Limitations of conventional biventricular pacing evolve around myocardial scar, fibrosis, and inability to effectively stimulate diseased tissue. Several observational and acute hemodynamic studies have demonstrated improved electrical resynchronization and echocardiographic response with conduction system pacing. This article provides a systematic review of conduction system pacing as a physiologic alternative to conventional CRT, which is currently undergoing rigorous investigation.

His-Optimized and Left Bundle Branch-Optimized Cardiac Resynchronization Therapy: In Control of Fusion Pacing **311**

Alwin Zweerink and Haran Burri

Fusion pacing, which exploits conduction via the intrinsic His-Purkinje system, forms the basis of recent cardiac resynchronization therapy (CRT) optimization algorithms. However, settings need to be constantly adjusted to accommodate for changes in AV conduction, and the algorithms are not always available (eg, depending on the device, in case of AV block or with atrial fibrillation). His-optimized cardiac resynchronization therapy (HOT-CRT), and left-bundle branch optimized cardiac resynchronization therapy (LOT-CRT) which combines conduction system pacing with ventricular fusion pacing, provide constant fusion with ventricular activation (irrespective of intrinsic AV conduction). These modalities provide promising treatment strategies for patients with heart failure, especially in those with chronic atrial fibrillation who require CRT (in whom the atrial port is usually plugged and can be used to connect the conduction system pacing lead).

Status and Update on Cardiac Resynchronization Therapy Trials **323**

Angelo Auricchio and Tardu Özkartal

After decades of clinical use, cardiac resynchronization therapy (CRT) can be considered an established therapy. However, there are multiple open questions to be addressed that shall further improve the proportion of patients responding to CRT. Progress in better understanding the relationship between electrical and mechanical disorder in patients with heart failure with ventricular conduction abnormalities is important. This article presents and discusses ongoing studies in different areas of CRT research, including patient selection by novel diagnostic tools, extension of clinical criteria, left ventricular lead positioning and pacing site selection, optimization of CRT delivery and programming, and selection of device type.

Generating Evidence to Support the Physiologic Promise of Conduction System Pacing: Status and Update on Conduction System Pacing Trials **345**

Nandita Kaza, Daniel Keene, and Zachary I. Whinnett

Conduction system pacing avoids the potential deleterious effects of right ventricular pacing in patients with bradycardia and provides an alternative approach to cardiac resynchronization therapy. We focus on the available observational and randomized evidence and review studies supporting the safety, feasibility, and physiologic promise of conduction system approaches. We evaluate the randomized data generated from the available clinical trials of conduction system pacing, which have led to the recent inclusion of CSP in international guidelines. Future randomized trials will build on the physiologic promise of conduction system pacing approaches and importantly, offer information on clinical endpoints.