Direct endoscopic visualization of physiological His-bundle pacing and surrounding anatomy within reanimated human hearts using visible heart methodologies

Alexander R. Mattson, PhD,*† Zhongping Yang, PhD,† Paul A. Iaizzo, PhD, FHRS*

*From the *Department of Surgery and the Institute for Engineering in Medicine, University of Minnesota, Minneapolis, Minnesota, and †Medtronic, Mounds View, Minnesota.*

Introduction

Permanent His-bundle pacing (HBP) is an attractive, perhaps more physiological, alternative to right ventricular pacing. However, optimization of this pacing approach requires the precise placement of a pacing lead onto the His bundle (HB), which is a branch of conductive fibers that extends from the distal atrioventricular node and runs along the membranous septum before diving into the ventricular septum. Furthermore, the anatomy of the HB varies among patients, potentially yielding different electrophysiological pacing profiles. Given that HBP capture may be achieved from either the atrial or ventricular side of the tricuspid annulus, there is discussion regarding the benefits and downsides of each.[1] We used direct visualization within reanimated human hearts to provide a comprehensive understanding of the anatomy central to HBP lead implantations.

Case reports

We present the reanimations of 2 nonviable human donor hearts, gifted to our laboratory for research via our local organ procurement agency (LifeSource, Minneapolis, MN). Detailed information regarding donated specimens, including video footage of specific anatomic features, can be found at the University of Minnesota's Atlas of Human Cardiac Anatomy free-access Web site (www.vhlab.umn.edu/atlas/) and is referenced by patient number. Notably, in both cases presented here, the reanimated hearts elicited intact atrioventricular conduction and nondiseased cardiac electrophysiology.

The donated hearts were reanimated using previously published Visible Heart methodologies.[2] In brief, isolated donor hearts were cannulated and connected to a closed-circuit external perfusion apparatus. Reperfusion of a clear modified Krebs–Henseleit buffer, coupled with a defibrillation shock, re-established cardiac function ex vivo. Endoscopic cameras (IplexFX, Olympus Corporation, Tokyo, Japan) placed within the heart allowed direct anatomic visualization during implants.

We instrumented each preparation to provide a surface electrocardiogram (ECG) analogue. Of note, ECG recordings in this study were acquired from leads placed directly adjacent to the heart, achieving electrical continuity through a conductive gel. Although analogous to clinical recordings, the electrical vectors shown in these cases were not precisely representative of a standard clinical ECG. In addition, temporary pacing leads implanted in the right atrial appendage and right ventricular outflow tract provided local right atrial and right ventricular electrograms.

A videoscopic landscape of the tricuspid annulus between the coronary sinus and anteroseptal tricuspid commissure was observed, to identify the approximate location of the HB. A 6-mm endoscope, placed into the root of the ascending aorta on the right coronary cusp, illuminated the membranous septum within the right atrium (Figure 1A). In each case, the HB was mapped using recordings from a 3830 lead (Medtronic, Minneapolis, MN) positioned using a C304 steerable sheath. Video recordings of both implant procedures can be found in the Supplemental Video.

Case 1

Patient 462 was a 53-year-old woman with a history of hypertension and mild calcification in the left anterior descending coronary artery. HB potentials were mapped, and HBP

KEYWORDS Electrophysiology; His-bundle pacing; His–Purkinje pacing; Visible heart; Visualization
(Heart Rhythm Case Reports 2019;5:209–212)

This study was designed and data were collected in collaboration with Medtronic, via a research contract. Dr Mattson, as a University of Minnesota student, completed data analysis and report writing, while Medtronic provided manuscript edits. The University of Minnesota provided the impetus to submit this manuscript for publication, with approval from Medtronic. Drs Mattson and Yang are Medtronic employees and have stock ownership in Medtronic. This research was funded through a research contract with Medtronic Plc. **Address reprint requests and correspondence:** Dr Paul A. Iaizzo, Department of Surgery and the Institute for Engineering in Medicine, University of Minnesota, 420 Delaware St SE, B172 Mayo, MMC 195, Minneapolis, MN 55455. E-mail address: iaizz001@umn.edu.

https://doi.org/10.1016/j.hrcr.2019.01.001

KEY TEACHING POINTS

- His-bundle pacing (HBP) provides an alternative to right ventricular pacing, but it requires the precise placement of a pacing lead onto the His bundle.
- Using direct visualization within reanimated human hearts, we provide an understanding of the anatomy central to HBP lead implantations.
- In both patient cases, selective HBP capture was achievable at low output, whereas fusion capture was seen at high outputs, suggesting lead placement within His–Purkinje tissues.

capture was achieved in only 1 location studied. The 3830 lead was implanted in this mapped location, just inferior to the most posterior segment of the membranous septum, on the atrial side of the tricuspid valve (Figure 1A). Native electrograms from the implanted lead placement showed a distinct His signature (Figure 1B). Selective HBP capture was achieved (Figure 1C). Thresholds were 1.7 V at 1.0-ms pulse width, 2.3 V at 0.5-ms pulse width, and 3.8 V at 0.2-ms pulse width. When pacing at 1.0-ms pulse width, fusion capture was observed at a voltage >7 V. QRS width was not significantly different between native sinus and selective HBP beats (103 vs 101 ms, respectively).

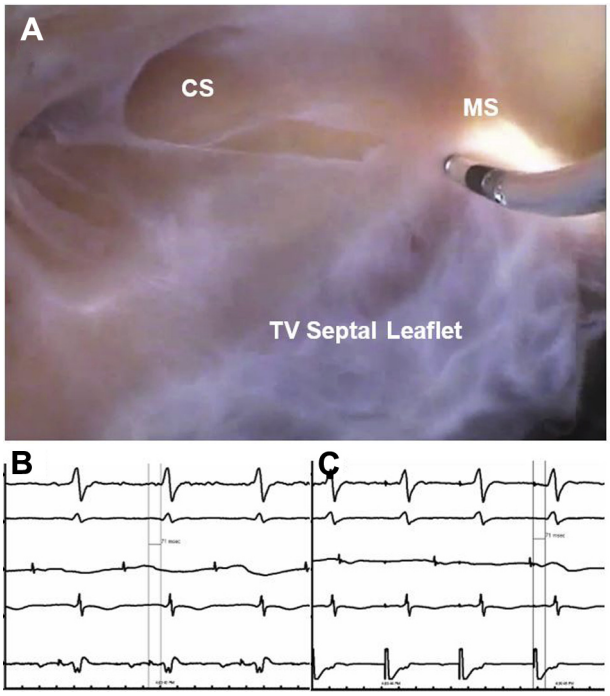

Figure 1 **A:** Endoscopic footage within the right atrium of patient 462. A Medtronic 3830 lead (Minneapolis, MN) was fixated just below the lower border of the membranous septum. **B, C:** Traces from top to bottom: electrocardiogram leads I, II, atrial electrogram (EGM), ventricular EGM, bipolar 3830 recording for native sinus beats. Atrial and ventricular EGMs were recorded via temporary pacing leads placed in the right atrial appendage and right ventricular outflow tract. CS = coronary sinus; MS = membranous septum; TV = tricuspid valve.

Case 2

Patient 475 was a 50-year-old woman with no salient cardiac history. In this reanimated heart, HBP capture was achieved in 2 separate locations, spanning the atrial and ventricular sides of the tricuspid valve. The first lead was implanted inferior to the proximal membranous septum on the atrial side of the tricuspid annulus (Figure 2A). Here, stable and selective HBP capture was seen (Figure 2E). Thresholds were 1.9 V at 1.0-ms pulse width, 2.8 V at 0.5-ms pulse width, and 4.2 V at 0.2-ms pulse width. Fusion capture was observed at outputs >6 V at 1.0-ms pulse width.

The second HBP lead was placed on the ventricular side of the tricuspid annulus, just below the membranous septum (Figure 2B). In this location, selective HBP capture was achieved at low output: 2.0 V at 1.0-ms pulse width, 2.3 V at 0.5-ms pulse width, and 6.3 V at 0.2-ms pulse width (Figure 2F). Again, fusion capture was found at higher outputs (3.0 V at 1.0-ms pulse width).

Discussion

In this study, we directly imaged the link between anatomic placement of HBP leads and electrophysiological behaviors. In both presented cases, an atrial lead position, just inferior to the most posterior visible segment of the membranous septum, achieved selective HBP capture. However, we were able to successfully map and pace the HB on the ventricular side of the tricuspid annulus in only 1 of 2 cases. In both patients, selective HBP capture was achievable at low outputs, whereas fusion capture was seen at high outputs, suggesting lead placement within His–Purkinje tissues.

Macroscopic anatomy of the HB was previously detailed by Kawashima and Sasaki.[3] In their study, HB anatomies were binned into 3 distinct anatomic categories:

1. Type I (47% of hearts). The HB is surrounded by a thin layer of myocardial tissue. The HB courses along the lower border of the ventricular membranous septum.
2. Type II (32% of hearts). The HB is insulated by a thicker layer of myocardial fibers. The HB runs separate from the lower border of the ventricular membranous septum, with a discrete separation between the two.
3. Type III (21% of hearts). The HB has no surrounding myocardial fibers (bare) and runs just beneath the endocardial surface, coursing onto the membranous portion of the ventricular septum.

It is hypothesized that anatomic variation may confer some of the variable selectivity of HB capture seen within clinical settings. In both presented cases, selective HBP capture was achievable on the atrial side of the tricuspid valve at low pacing output, with nonselective HBP capture at higher outputs.

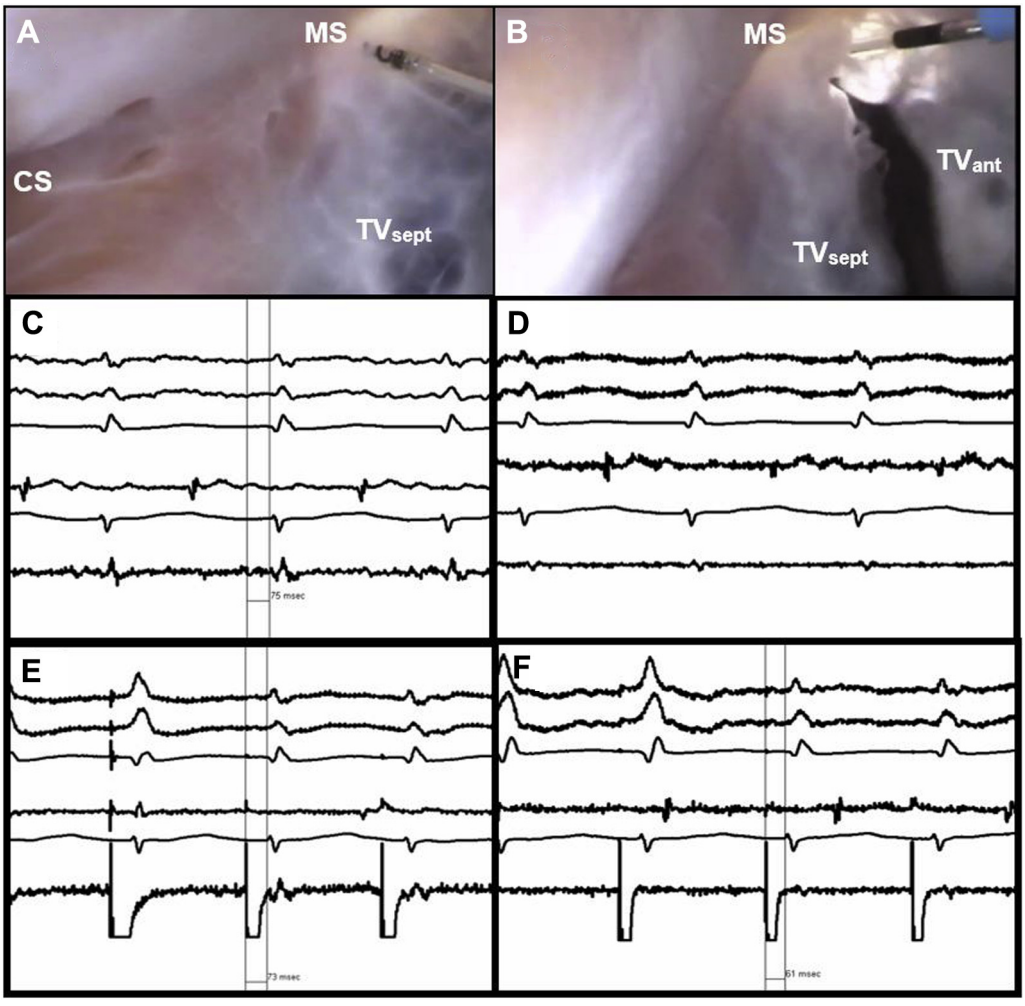

Figure 2 **A, B:** Endoscopic footage of Medtronic 3830 lead implants (Minneapolis, MN) on the atrial and ventricular sides of the tricuspid annulus of patient 475. Both leads were placed along the lower border of the membranous septum. **C, D:** Native electrical signatures for each lead placement. Traces from top to bottom: electrocardiogram leads I, II, and III, atrial electrogram (EGM), ventricular EGM, 3830 bipolar EGM. **E, F:** Selective His-bundle pacing capture was achieved for both lead placements. Traces from top to bottom: electrocardiogram leads I, II, and III, atrial EGM, ventricular EGM, 3830 bipolar EGM. CS = coronary sinus; MS = membranous septum; TVant = anterior tricuspid valve leaflet; TVsept = septal tricuspid valve leaflet.

In the case of patient 462, HBP capture was not achieved on the ventricular half of the tricuspid annulus. As such, the HB anatomy in this patient is unlikely to be a type III variant, in which an area on or near the membranous septum would likely exhibit large HB potentials in addition to low-output selective HBP capture threshold.

Based on imaging and electrophysiological data, patient 475 was likely a type I anatomic variant. The ventricular HBP lead in this patient was placed just below the membranous portion of the ventricular septum, consistent with a type I anatomic variant. At low output (1.9 V, 1.0-ms pulse width), selective HBP capture was achieved. Heightened output (3.0 V, 1.0-ms pulse width) yielded nonselective HBP. The transition of selective to nonselective HBP as output rises is characteristic of both type I (generally occurring with a small difference in output) and type III (occurring with a large difference in pacing output) anatomies. Here, the relatively large output differential between selective and nonselective HBP may suggest a type III anatomy. However, in a type III anatomy, prominent HB potentials are expected on or near the membranous septum. Here, HB potentials were small enough to be obscured by electrical noise on the lead electrogram (Figure 2C and D). Thus, most evidence in this case indicates a type I anatomy.

Notably, the electrical signal morphologies and pacing capture thresholds presented here were collected on reanimated cardiac specimens. Correlations to true clinical electrophysiology are undefined.

Conclusion

In these unique reanimation studies, direct visualization aided in the precise positioning and utilization of the leads; in fact, live video was the primary imaging modality used for these lead placements. Although lead placement using direct visualization is not representative of visualization techniques available in the clinical setting, the images

presented here should have notable educational value for both clinicians and design engineers.

Appendix

Supplementary data

Supplementary data associated with this article can be found in the online version at https://doi.org/10.1016/j.hrcr.2019.01.001.

References

1. Mattson AR, Mattson E, Mesich ML, Yang Z, Iaizzo PA. Electrical parameters for physiological His–Purkinje pacing vary by implant location in an ex vivo canine model. Heart Rhythm 2019;16:443–450.
2. Chinchoy E, Soule CL, Houlton AJ, et al. Isolated four-chamber working swine heart model. Ann Thorac Surg 2000;70:1607–1614.
3. Kawashima T, Sasaki H. A macroscopic anatomical investigation of atrio-ventricular bundle locational variation relative to the membranous part of the ventricular septum in elderly human hearts. Surg Radiol Anat 2005;27:206–213.