First-in-human combined transcatheter tricuspid valve implantation with leadless VDD pacemaker via left internal jugular approach

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Introduction
Percutaneous valve-in-valve tricuspid valve replacement has been an effective treatment for bioprosthetic tricuspid valve degeneration for over a decade.1 Cardiovascular implantable electronic device (CIED) indications in this patient group are common, and many patients being considered for valve-in-valve replacement have 1 or more endocardial ventricular leads. These present the operator with the choice to extract and replace transvalvular leads, or to entrap them between the valve stent and ring. Entrapment of a lead renders future extraction impossible in the case of infection, and may shorten the life of the lead.2 But even the replacement of a transvalvular CIED lead can contribute to tricuspid valve dysfunction,3 accelerating the time to reintervention. In young patients, such as the patient with congenital heart disease described here, this decision could feasibly result in multiple additional procedures, and their attendant risks, over a lifetime.

Leadless pacemaker (LP) systems are entirely contained in the right ventricle, with no leads across the tricuspid valve, thereby avoiding these concerns. Reports describing LP implantation in patients after recent tricuspid valve repair or replacement4,5 cite a similar justification for their use. While LPs have been successfully implanted in young patients, from varying approaches,6,7 and in unusual anatomic situations,8 there are no reports of LP implantation through a percutaneously implanted tricuspid valve. Concerns with a percutaneous valve placement compared to a surgical prosthesis include the potential for valve dislodgment and embolism, particularly with a newly implanted valve. Here, we report successful transvenous dual-chamber pacemaker extraction, percutaneous valve-in-valve tricuspid valve replacement, and leadless VDD pacemaker implantation in a single procedure.

Case report
The patient is a 28-year-old man with a history of complete atroventricular (AV) septal defect repaired in infancy, with a postoperative course complicated by extracorporeal membrane oxygenation, and residual right and left AV valve regurgitation and stenosis. At age 21, he underwent bioprosthetic tricuspid valve replacement (#25 Mosaic; Medtronic, Minneapolis, MN) and mechanical mitral valve replacement (#29 Carbomedics; LivaNova, London, UK), which was complicated by surgical complete heart block. A transvenous dual-chamber pacemaker with Medtronic model 3830 leads was implanted postoperatively. In addition, he experienced heparin-induced thrombocytopenia with multiple venous thromboses leading to a prolonged hospitalization.

In the subsequent years, he developed progressive tricuspid stenosis, with restricted motion of the prosthetic valve leaflets, and mean in-flow gradient of 12–17 mm Hg. The mitral valve was functioning well, and the patient was compliant with warfarin anticoagulation. He was pacemaker-dependent, with no underlying rhythm at VVI 30. The pacemaker was functioning well, although a loop of atrial lead prolapsed across the tricuspid valve. After counseling and multidisciplinary conferences, owing to the history of multiple prior sternotomies and previous postoperative complications, both patient and provider preference was for percutaneous tricuspid valve-in-valve implantation (Edwards Sapien S3; Edwards Lifesciences, Irvine, CA), preceded by pacemaker extraction and reimplantation of a VDD LP (Micra AV™; Medtronic, St. Paul, MN), as opposed to open surgical repair.

Preoperative testing for heparin-induced thrombocytopenia antibodies was negative, and hematology consultation
suggested that a short duration of unfractionated heparin therapy would be well tolerated. Oral anticoagulation was held with low-molecular-weight heparin bridge. Although preoperative venous ultrasound suggested a patent left femoral vein, at the procedure, occlusion of the infrarenal inferior vena cava was diagnosed. The right internal jugular vein had been previously inaccessible, presumably owing to extracorporeal membrane oxygenation in infancy.

A 12F sheath placed in the left internal jugular (LIJ) vein, and through it a wire was advanced to the inferior vena cava for emergent access during extraction. Temporary pacing was established via a 5F quadripolar pacing catheter placed in the left ventricle (LV) retrograde via the left femoral artery. The left prepectoral pacemaker pocket was opened, and 2 wires were placed in the left axillary vein in the case of inability to implant the LP. Both chronic leads were found to be firmly held by fibrous attachments. They were extracted utilizing a 14F laser sheath (Spectranetics Inc, Colorado Springs, CO) and Bulldog lead extension (Cook Medical, Bloomington, IN), without complication.

After hemodynamic stability was assured, percutaneous tricuspid valve implantation was performed. The patient received systemic anticoagulation with heparin, with a goal activated clotting time >250 seconds for this portion of the procedure. The 12F LIJ sheath was exchanged for the 14F Edwards e-sheath and, ultimately, a 24F Dryseal sheath for successful implantation. A Lunderquist wire in the right pulmonary artery (RPA) supported valve preparation with serial balloon dilation and fracture of the valve ring, ultimately with a 24 mm high-pressure balloon. High-rate (180 beats/min) ventricular pacing via the LV pacing lead was utilized to temporarily decrease cardiac output to aid in stability during balloon inflation. A 26 mm Edwards Sapien S3 valve was successfully delivered in a stable position and postdilated with a 24 mm high pressure balloon. A 2 mm Hg gradient was measured across the new valve, with trivial angiographic regurgitation and no perivalvular leak (Figure 1).

With tricuspid valve implantation completed, LP implantation was performed under fluoroscopic guidance. The Lunderquist wire in the RPA was used to exchange the 24F sheath for the 27F Micra introducer sheath. An attempt was made to pass the sheath through the valve to the right ventricle over the wire, with the goal of unsheathing the Micra delivery catheter in the right ventricle to protect the valve from catheter manipulations. However, the interaction between the dilator tip and inferior aspect of the newly implanted valve threatened valve dislodgement despite a manual curve placed on the Micra introducer sheath and dilator (Figure 2A). Therefore, the wire and dilator were removed, with the tip of the Micra introducer sheath in the superior right atrium. The LP delivery catheter was readily deflated and advanced through the tricuspid valve to the right ventricle (Figure 2B). A Micra AV was successfully deployed in a midseptal position on the first attempt (Figure 2C–2F). Testing of the device confirmed excellent threshold and impedance measures (0.5 V at 0.24 ms, 650 ohms, respectively), and a tug test confirmed engagement of at least 2 of 4 tines. The LV paced rhythm was sensed at 3.8 mV. The prepectoral pocket was closed, and 20 minutes of manual pressure was sufficient to obtain hemostasis at the internal jugular access site without the use of a vascular closure device.

Echocardiogram the following day revealed trivial tricuspid regurgitation and trivial stenosis (mean gradient 3–7 mm Hg), with a tricuspid E:A ratio of 2:1. A 12-lead electrocardiogram showed 100% capture and intermittent AV synchrony (Figure 3A). At 1 week follow-up, AV synchronous pacing was limited to 37.4% in VDD 50–120.

### KEY TEACHING POINTS

- Leadless pacemakers can be considered as an alternative to a traditional pacemaker system in patients with percutaneous tricuspid valve replacements to avoid interaction of the valve leaflets with pacemaker leads.
- Atrioventricular synchrony with the Micra AV (Medtronic, St. Paul, MN) can be achieved in patients with bioprosthetic valves, although extensive optimization may be needed.
- A left internal jugular vein approach for leadless pacemaker implantation is feasible and offers familiarity in operator hand positioning and movements.
Figure 2  Fluoroscopic views of Micra AV (Medtronic, St. Paul, MN) implantation procedure. A: Attempting to cross the newly implanted tricuspid valve with the Micra sheath over a stiff wire in the right pulmonary artery was unsuccessful, although B: the Micra delivery catheter was easily navigated through the tricuspid valve stent. The left internal jugular approach facilitated familiar catheter movements. C: Right anterior oblique (RAO) and D: steep left anterior oblique (LAO) views of positioning the Micra on the interventricular septum; note contrast “pancaking” on the septum. E: Unsheathing the Micra. F: Final position of the Micra in the right ventricle. Temporary pacing catheter in the left ventricle via retrograde aortic approach can also be seen throughout. CAUD = caudal angulation; CRAN = cranial angulation.
Atrial mechanical pressure as sensed by the device was low, and low A4 amplitude was the main barrier to lack of consistent AV synchrony. Accelerometer sensing vector was adjusted, the A4 threshold was decreased, and lower rate limit was increased to 60. Repeat interrogation 2 months after implant reported 52% AV synchronous pacing, but A4 over- and undersensing was observed (Figure 3B). The patient was feeling well at this visit and reported no activity limitations. Further adjustments to A3 threshold and window and A4 threshold were made. Interrogation at 5 months after implant revealed 79% AV synchronous pacing, although some degree of over- and undersensing persisted (Figure 3C).

**Discussion**

To our knowledge, this is the first reported case of an LP deployed through a percutaneously implanted tricuspid valve. Moreover, both the LP and the tricuspid valve were implanted via the LIJ vein, which has also been rarely reported. No major modifications to the LP implantation procedure were required, making it relatively straightforward in the hands of an experienced operator. In fact, an LIJ approach may offer benefits over the right side owing to ease of operator positioning and familiarity of hand movements on the delivery catheter that would otherwise be switched coming from the right. The tricuspid valve was rehabilitated, and a
reliable ventricular pacing was obtained without a multiplemode open cardiac surgery.

Selection of an LP in this case confers several potential benefits compared to a traditional pacemaker system. First, there is no lead to interact with valve leaflets, which may result in improved long-term valve function. Although not studied in percutaneous tricuspid valves, the negative impact of CIED leads on tricuspid valve function has been previously described.\(^3\) Given the limited durability of bioprosthetic AV valves, it is likely that repeat tricuspid valve intervention will be needed in this young man, and extending time between valve interventions is valuable. Second, the lack of a transvenous lead across the tricuspid valve will allow for future valve interventions without the need for extraction. Although the safety of percutaneous extraction has dramatically improved, the risk of serious complications remains. Jailing the lead has been described in this setting without impaired lead function at limited follow-up,\(^9,10\) but this prevents future percutaneous extraction options.\(^11\)

Lastly, LPs have a low rate of infection, which may mitigate the risk of endocarditis in this patient with multiple prosthetic valves, including in the systemic circulation.\(^12\)

Although clear benefits of LP exist in this situation, challenges with AV synchronous pacing may be a drawback. The impact of AV synchrony in congenital hearts may be particularly important. With Micra AV, atrial-synchronous ventricular pacing (VDD mode) is achieved by sensing the mechanical force of atrial contraction with a 3-axis accelerometer. This algorithm has been shown to be effective, with 95% of the MARVEL2 cohort with complete AV block achieving >70% AV synchrony with this technology.\(^13\)

Although our patient initially did not achieve this level of AV synchrony, optimization of the sensing vector, lower rate limit, windows, and gating has allowed for a high degree of AV synchrony despite low atrial mechanical pressure, though A4 under- and oversensing persist. Preprocedure screening echo for E/A ratio has been shown to predict AV synchrony but may not be predictive of right ventricular filling dynamics in our patient owing to tricuspid stenosis. It may have been possible to establish AV synchronous pacing and evaluate E/A ratio after tricuspid replacement intraoperatively to estimate response prior to implant. However, with rate-responsive pacing based on the accelerometer available as a programming option, the lack of AV synchrony may not manifest with clinical limitations, and it is unlikely that this alone would have changed the decision to implant an LP. Further, true AV-synchronous LPs are presently in development. Fortunately, the patient does not perceive activity intolerance in early follow-up.

As pacing will be needed throughout this patient’s lifetime, it is important to consider how an LP affects future options when the device reaches end of life. Although LPs become encapsulated with endocardium after approximately 6 weeks, experience with percutaneous retrieval of chronic LPs is growing, with encouraging results.\(^15\) If an LP is unable to be percutaneously extracted, a second LP could be implanted without compromising the right ventricle cavity or valve function. The serial LPs could be extracted directly at the time of any future open heart operation. Lastly, conversion to a traditional dual-chamber transvenous device remains an option.

**Conclusion**

Implantation of an LP through a newly implanted percutaneous tricuspid valve is feasible, limiting concern for lead-related tricuspid valve dysfunction and providing ability to perform additional tricuspid valve procedures without lead extraction. Furthermore, this procedure can be achieved from the LIJ vein when no other central access is available.

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