9-17-2021

Initial in-human experience with the conveyor cardiovascular system for the delivery of large profile transcatheter valve devices

Brian P. O'Neill
Henry Ford Health, boneil3@hfhs.org

Dee Dee Wang
Henry Ford Health, dwang2@hfhs.org

Thomas G. Caranasos

W. Randolph Chitwood

William W. O'Neill
Henry Ford Health, woneill1@hfhs.org

See next page for additional authors

Recommended Citation

O'Neill BP, Wang DD, Caranasos TG, Chitwood WR, Jr., O'Neill WW, and Stack R. Initial in-human experience with the conveyor cardiovascular system for the delivery of large profile transcatheter valve devices. Catheter Cardiovasc Interv 2021.

Authors

Brian P. O'Neill, Dee Dee Wang, Thomas G. Caranasos, W. Randolph Chitwood, William W. O'Neill, and Richard Stack

Received: 14 May 2021 | Revised: 2 September 2021 | Accepted: 6 September 2021

DOI: 10.1002/ccd.29956

ORIGINAL STUDIES

WILEY

Initial in-human experience with the conveyor cardiovascular system for the delivery of large profile transcatheter valve devices

Brian P. O'Neill MD[1,2] | Dee Dee Wang MD[1,2] | Thomas G. Caranasos MD[1,3] | W. Randolph Chitwood Jr. MD[1,4] | William W. O'Neill MD[1,2] | Richard Stack MD[1,5,6,7]

[1]Cardiovascular Masters Consortium, Durham, North Carolina, USA

[2]Center for Structural Heart Disease, Henry Ford Hospital, Detroit, Michigan, USA

[3]Department of Surgery, UNC Chapel, Chapel Hill, North Carolina, USA

[4]Department of Surgery, East Carolina University, Greenville, North Carolina, USA

[5]Department of Medicine, Duke University, Durham, North Carolina, USA

[6]Synecor, LLC, Chapel Hill, North Carolina, USA

[7]Conveyor Cardiovascular Ltd, Dublin, Ireland

Correspondence
Brian P. O'Neill, Center for Structural Heart Disease, Henry Ford Hospital, 2799 W. Grand Blvd, Detroit, MI, USA.
Email: boneil3@hfhs.org

[Correction added on 17 October 2021, after first online publication: Edits have been made to this version. None of the edits affect the meaning of the content.]

Abstract

Objectives: To determine the safety and efficacy of the conveyor cardiovascular system (CCS) to facilitate the delivery of large profile transcatheter valve devices.

Background: Transcatheter valve devices rely on force provided by the operator to be delivered to their intended position. This delivery may be challenging in a variety of anatomic scenarios. The ability to provide steering from the tip of the device by forming an arterial venous loop may help overcome these challenges.

Methods: Between May, 2019 and October, 2020, five patients were recruited for delivery of transcatheter valve devices with the CCS. These patients were deemed by the operators to have challenging anatomy which could make conventional valve delivery difficult or impossible. These patients were recruited as part of an FDA approved early feasibility study or through an institutional review board approved compassionate use protocol.

Results: Three patients underwent transcatheter mitral valve replacement with a SAPIEN-3 valve. One patient each underwent transcatheter aortic valve (TAVR) implantation with a SAPIEN 3 and 1 patient underwent TAVR implantation with a Lotus valve. All patients underwent successful implantation of the valve and removal of the CCS and valve delivery systems. There was no more than trivial mitral regurgitation post procedure in any patient and there was no more than trivial paravavular leak. There were no major in-hospital complications.

Conclusions: The CCS facilitates the delivery of large profile transcatheter valve devices in challenging anatomic scenarios. Further studies are needed with additional valve technologies.

KEYWORDS
antegrade, aortic, mitral, TAVR, TMVR, transeptal

1 | INTRODUCTION

The advent of transcatheter technology has forever changed the landscape of the treatment of structural heart disease. Recently, transcatheter aortic valve replacement (TAVR) has supplanted surgical aortic valve replacement (SAVR) as the most common treatment for patients with aortic stenosis in the United States.[1] Multiple different devices for both mitral and tricuspid valve replacement are in clinical trials and it is likely these too may 1 day eclipse the number of surgical interventions. A commonality in each of these technologies is the

reliance on advancing and steering large profile devices from behind using guide wires and/or steerable sheaths (retrograde steering) most commonly from the femoral artery or vein to the targeted valve. In the aortic position, several commonly encountered anatomic variances may make this method of delivery challenging. These would include a horizontal aortic arch, aortic aneurysm, and bicuspid valves, particularly those which are heavily calcified with fused raphe, valve in valve or small annuli. In the mitral position, a thickened interatrial septum, which is commonly found in post-surgical patients, and inadequate transeptal height may lead to injury or tearing of the septum. High profile delivery systems may need to navigate an extreme angle to reach the mitral valve annulus within the left atrium. These can also lead to challenges in maintaining a co-axial position.

A potential solution to these challenges is the ability to steer large profile devices from the front (antegrade steering) with the formation of a specialized, protected atrioventricular (AV) loop. This technique is well known in the field of paravalvular leak (PVL) closure, where serpiginous leaks may preclude the retrograde delivery of closure devices. However, the experience with TAVR has been mixed. The first cases of TAVR relying on antegrade valve delivery resulted in 1/3 of patients requiring CPR during the manipulation across the aortic valve.[2] As a result of this, antegrade delivery has been reserved for those patients principally with no other peripheral access, eliminating the potential advantages of this system in those aforementioned challenging anatomic TAVR cases.[3]

Much of the hemodynamic instability seen in these cases is due to a stiff wire across the aortic and mitral valve resulting in simultaneous aortic and mitral insufficiency. Dedicated devices to allow for the efficient creation of an AV loop that could provide antegrade steering without hemodynamic instability are therefore needed to help overcome the challenges of retrograde steering. We present our initial experience with the conveyor cardiovascular system (CCS) (Conveyor Cardiovascular Ltd, Dublin, Ireland) for delivery of transcatheter devices in challenging anatomy.

2 | METHODS

Patients with aortic or mitral valve disease were recruited as part of an FDA approved early feasibility study (sponsored by Synecor LLC, Durham, NC, United States) or through an institutional review board approved compassionate use protocol. Each patient underwent informed consent prior to their procedures. Inclusion criteria were technical factors which in the opinion of the operators would make conventional retrograde delivery of transcatheter devices extremely challenging or would be associated with higher complications. These scenarios included a horizontal aortic arch and bicuspid valve with bulky calcification in the aortic position, and anticipated challenges with septal crossing or co-axiality within the surgical mitral valve prosthesis in the mitral position. Possible complications could include PVL, the need for permanent pacemaker implantation, injury to the ascending aorta, and injury to the interatrial septum or left ventricle (LV). Patients who met these criteria underwent valve implantation with assistance of the CCS.

The components of the CCS are listed in Figure 1. The system consists of the following three subcomponents: the right-to-left conduit (RLC) (Figure 1A); the conveyor cable (Figure 1B); and the left ventricular redirector-low profile sheath (LVR-LPS) with dilator (Figure 1C). A transeptal puncture is performed in the standard fashion (Figure 2A). A Versacore (Abbott, Abbott Park, IL, United States) guidewire is introduced into the left atrium and a balloon septostomy is performed with a 12 mm septostomy balloon (Figure 2B). The transeptal sheath is removed and the RLC is advanced into the left atrium beyond the mitral valve orifice. The tip of the RLC is then flexed and pulled back, while applying counter clockwise torque, until it crosses into the mitral valve. The system is then advanced and curled until the tip points toward the aorta. The Versacore is advanced into the aorta followed by the RLC (Figure 2C). The Versacore wire is snared from the left femoral artery (Figure 2D) and the RLC is removed and exchanged briefly for the septostomy balloon, as it is advanced through the chords to confirm no chordal entrapment of the system. The RLC is then readvanced into the distal aorta over the Versacore wire. The Versacore wire is removed and replaced by the Conveyor Cable which is then snared and externalized. At this time the arterial sheath is removed and the LVR sheath and dilator is locked into the conveyor cable. The cable is then pulled from the venous side allowing the LVR to easily track into the descending aorta and lock onto the RLC (Figure 2E). With a push pull method the LVR is then positioned in the apex of the LV and the RLC is released. The LVR features a high force retracting guy wire (Figure 1C) that provides for the strong antegrade steerability of the conveyor cable in the LV in

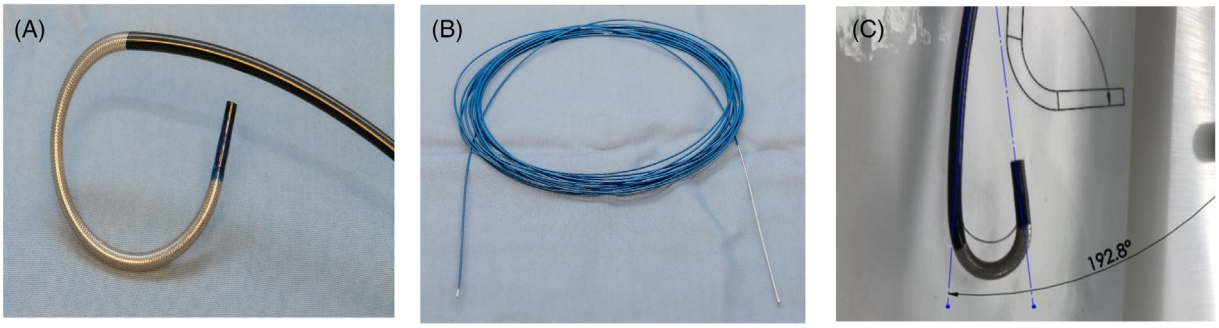

FIGURE 1 Conveyor cardiovascular system. (A) Right to left catheter (RLC). (B) Conveyor cable. (C) Left ventricular redirector (LVR) [Color figure can be viewed at wileyonlinelibrary.com]

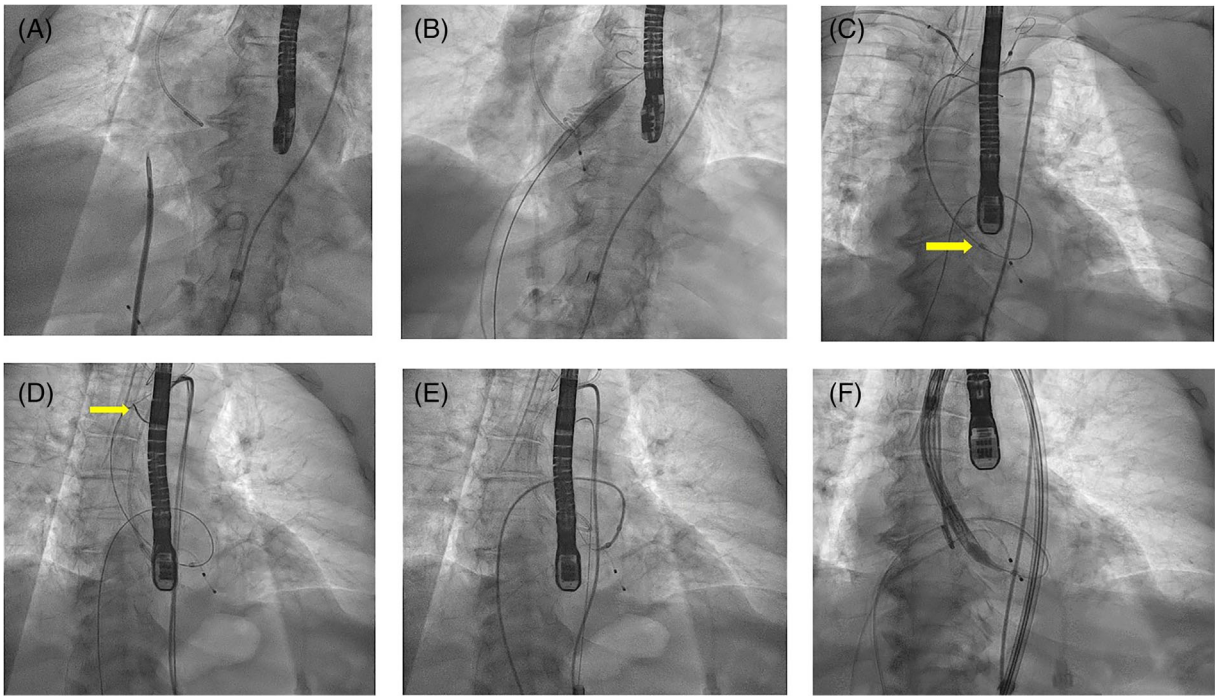

FIGURE 2 Procedural steps in creating arterial–venous (AV) loop with the conveyor system. (A) Standard transeptal puncture. (B) Balloon septostomy to allow catheter passage. (C) Versacore wire is advanced into the ascending aorta. (D) Versacore wire is snared to create AV rail allowing exchange of right-to-left conduit (RLC). (E) Connection of the RLC and left ventricular redirector (LVR). (F) Pulling on conveyor cable allows the LVR to pull valve nose cone away from outer curvature of arch to center in the annulus [Color figure can be viewed at wileyonlinelibrary.com]

TABLE 1 Baseline characteristics

	% (N = 5 overall)
Age (years)	68.4
STS score	9.0 ± 7.6
Male	20 (1)
NYHA class III or IV	40 (2)
HTN	80 (4)
Diabetes	20 (1)
End stage renal disease	20 (1)
Prior cerebrovascular accident	20 (1)
COPD	20 (1)
Prior MI	20 (1)
Prior CABG	20 (1)
Atrial fibrillation	40 (2)
Prior permanent pacemaker	40 (2)
Left ventricular ejection fraction (%)	62.6 ± 6.1

Abbreviations: CABG, coronary artery bypass grafting; COPD, chronic obstructive pulmonary disease; DMII, type; MI, myocardial infarction; NYHA, New York Heart Classification; STS, Society of Thoracic Surgeons.

order to facilitate centering of the large valve prosthesis within the intended valve annulus (Figure 2F), Video S1. Additionally, the LVR while positioned in the left ventricular apex, protects the apex from trauma or perforation due to the valve delivery systems or cable.

3 | RESULTS

From March, 2019 to October, 2020, five patients were recruited. Table 1 shows patient baseline characteristics. The majority of patients who were treated were female. Most patients were not on dialysis and had a normal left ventricular ejection fraction. Two of five patients had a previous pacemaker placement and had atrial fibrillation. Table 2 shows the characteristics of valve implantation. Three of five patients underwent implantation for a degenerated mitral valve prosthesis in previous surgical valves, with two of these patients having previously had more than one mitral valve intervention. The other two patients underwent implantation for native aortic valve stenosis. The rationale for utilization of the CCS in each of these procedures is also listed in Table 2. For the mitral valve cases, the device would assist in transit across the thickened septum to avoid tearing, and to help maintain co-axiality within the mitral valve prothesis. For the aortic valve cases the device would allow passage across the calcified raphe of the bicuspid valve and to keep the valve centered, given the horizontal nature of the aortic arch. In all patients, the transcatheter valve was successfully delivered into the intended position and the CCS and valve delivery system were removed without incident. There were no major adverse cardiovascular events as per Valve Academic Research Consortium definitions.[4] In the aortic stenosis patients, there was no need for permanent pacemaker implantation.

Post echocardiographic variables are shown in Table 3. There was no more than trivial mitral regurgitation in both the aortic and mitral

TABLE 2 Characteristics of valve implantation

Patient	Aortic or mitral valve disease	Native or post-surgical valve disease	Rationale for conveyor use	Valve type	Successful valve delivery (y/n)	Major VARC complications in hospital (y/n)
1	Mitral	Surgical (MVRx2)	Transit across septum and delivery	29 mm SAPIEN 3	y	n
2	Mitral	Surgical (MV Repair and TMVR)	Transit across septum and delivery	23 mm SAPIEN 3	y	n
3	Aortic	Native	Horizontal root and bicuspid	29 mm SAPIEN 3	y	n
4	Aortic	Native	Horizontal root and bicuspid	27 mm LOTUS EDGE	y	n
5	Mitral	Surgical (MVRx1)	Transit across septum and delivery	29 mm SAPIEN 3	y	n

Abbreviations: mm, millimeter; MVR, mitral valve replacement; N, no; TMVR, transcatheter mitral valve replacement; VARC, Valve Academic Research Consortium; y, yes.

TABLE 3 Echocardiographic procedure results

Patient	Baseline mean gradient (mmHg)	Baseline valve area (cm^2)	Post mean gradient (mmHg)	Post valve area (cm^2)	Mitral regurgitation Pre	Mitral regurgitation Post	Paravavular leak
1	14.3	n/a	3.8	n/a	None	Trivial	None
2	11.1	n/a	10.3	n/a	None	None	None
3	41.9	0.78	9.8	1.93	Trivial	Trivial	None
4	30.5	0.82	11.6	2.25	Mild	Trivial	None
5	19.3	n/a	9.3	n/a	None	Trivial	None

Abbreviation: n/a = not applicable.

valve patients post valve implantation. Post-procedure mean gradients were decreased from baseline in both groups of patients. Finally, there was no evidence of PVL in any patients.

4 | DISCUSSION

Our series represents the initial experience with the CCS for the delivery of large bore, high profile transcatheter valve devices. Several important insights emerge from this study.

With respect to aortic stenosis, the delivery of transcatheter valves in horizontal roots may be assisted by the CCS. TAVR is hampered by increasing aortic root angulation principally due to challenges of alignment within the valve annulus. This may cause the need for multiple valve repositionings, recaptures, or deployment of the valve in a non-coaxial fashion leading to paravavular regurgitation.[5] Previous studies have shown that 30% of patients have an aortic root angle of >50. Real world experience with horizontal roots greater than 51^0 with self-expanding valves has shown an increased rate of stroke and major vascular complications in a single center study,[6] and aortic angulation may impact procedural success with self-expanding valves vs. balloon expanding valves.[7] The inability to control the valve by retrograde steering may be partially overcome through snaring of the valve delivery system prior to deployment, however, this force cannot be applied to the valve tip.[8] The ability to move the valve from the tip with the CCS may allow the valve to be moved off the outer curvature of the aorta and to center the valve within the annulus for deployment which may help address some of these challenges (Figure 3).

Heavily calcified bicuspid valves remain a challenging scenario in TAVR. Accounting for half of younger patients who undergo SAVR,[9] TAVR operators are more commonly encountering patients with biscuspid aortic valve disease. In a multi-center study of more than 1000 patients with biscuspid AS treated predominantly with a balloon expandable valve, 26% had both a calcified raphe and excess leaflet calcification. These patients had higher rates of 2-year all-cause mortality, aortic root injury, and moderate-to-severe PVL.[9] The asymmetric calcium distribution along with fused raphe may lead to difficulties with advancing the valve across the annulus and with optimal

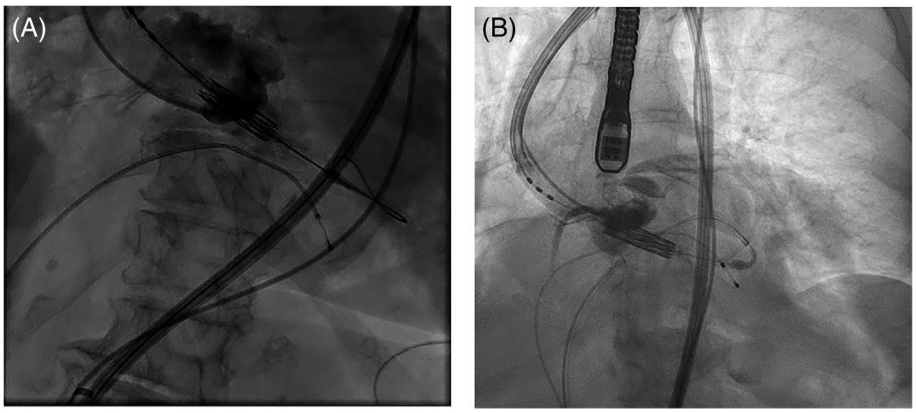

FIGURE 3 Transcatheter aortic valve (TAVR) deployment in horizontal roots. (A) Conventional TAVR deployment in a horizontal root of 78°. The TAVR valve pressed against the membranous septum. (B) TAVR deployment in a root of 70° with the conveyor system. Here the valve is off the membranous septum just before valve deployment

expansion of the outer valve frame.[10] In addition, narrowing of the aortic valve complex above the true annulus can lead to a less circular deployment,[11] which can be more challenging with self-expanding valves. The AV rail created by the CCS may help maintain the central position of the valve during deployment to allow for a more uniform distribution of force.

Conduction disturbances remain a frequently encountered challenge post TAVR and have been associated with a higher incidence of death or heart failure admission at 1 year.[12] Studies have consistently shown that long framed self-expanding valves are particularly prone to conduction disturbances post TAVR.[13,14] This is partially due to their inability to self-center, causing compression of the membranous septum during expansion. Calcifications in the LVOT under the left coronary cusp are thought to lead to higher rates of pacemaker dependency through a similar mechanism of valve expansion toward the septum.[15,16] Although a higher implantation depth may obviate some of this risk, the initial positioning may still cause trauma.[14] The CCS may help avoid this initial injury once more through maintaining a centralized position during valve delivery and expansion.

Transcatheter mitral valve replacement (TMVR) has shown promise in several early feasibility studies.[17,18] Given the size of the delivery equipment required however, many of these systems require a transapical approach. A transeptal delivery system is ideal to avoid the need for a transapical exposure in patients with multiple co-morbidities. Transeptal delivery is not without its challenges. Accessing the left atrium through the interatrial septum with a large device can lead to unexpected movements into either the left atrium or ventricle which may cause injury. As compared with TAVR, delivery devices for TMVR are larger profile which can limit maneuverability within the left atrium. Steerable guiding catheters may help to partially overcome this but may then limit maneuverability given stored torque.[19] The creation of a specialized arterial–venous (AV) loop is one way to address these shortcomings.

The concept of the traditional AV loop is well familiar to those operators who routinely perform PVL closure to facilitate delivery of closure devices.[20] Antegrade transeptal delivery of first generation TAVR valves was feasible in a case series of patients with aortic stenosis and no other suitable vascular access.[3] The advantages of this technique include the ability to apply force to both sides of the device in order to navigate the smaller space of the left atrium. The continuous loop may prevent unintended movement of the nose cone of the delivery system from inadvertent injuries of the delicate portions of the heart. The unique design of the CCS cable (braided coating and polymer jacket) coupled with the anterograde steering force of the LVR prevents interaction with the leaflets of the aortic and mitral valve leaflets which may lead to hemodynamic instability by causing severe mitral and/or aortic regurgitation.

5 | LIMITATIONS

This was a pilot study of a novel system to facilitate percutaneous valve delivery. As such, these findings are hypothesis generating and will need to be confirmed in future studies. In addition, this was a single center study and events were self-adjudicated. There was no central core lab to review echocardiographic results.

6 | CONCLUSIONS

The CCS may facilitate transcatheter valve delivery in patients who were deemed to have challenging structural anatomy. This pilot study demonstrated the feasibility of incorporating this system with multiple different transcatheter valves. Future studies in a broader representation of patients are warranted.

CONFLICT OF INTEREST

Dr Brian O'Neill is a consultant to and receives research support from Edwards Lifesciences. Dr Wang is a consultant for Edwards Lifesciences, Boston scientific, and receives research grant support from BSCI assigned to employer HFHS. Dr Stack serves as Executive Director for Conveyor Cardiovascular Ltd and Managing Partner of Synecor, LLC. He was involved in the editing of the manuscript but the final version was left to the discretion of the first author. The other authors have no additional relevant disclosures to report.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

ORCID

Brian P. O'Neill https://orcid.org/0000-0001-5206-1639
Dee Dee Wang https://orcid.org/0000-0002-5784-9924

REFERENCES

1. Carroll JD, Mack MJ, Vemulapalli S, et al. STS-ACC TVT registry of transcatheter aortic valve replacement. J Am Coll Cardiol. 2020;76(21):2492-2516.
2. Cribier A, Eltchaninoff H, Tron C, et al. Early experience with percutaneous transcatheter implantation of heart valve prosthesis for the treatment of end-stage inoperable patients with calcific aortic stenosis. J Am Coll Cardiol. 2004;43(4):698-703.
3. Cohen MG, Singh V, Martinez CA, et al. Transseptal antegrade transcatheter aortic valve replacement for patients with no other access approach—a contemporary experience. Catheter Cardiovasc Interv. 2013;82(6):987-993.
4. Kappetein AP, Head SJ, Genereux P, et al. Updated standardized endpoint definitions for transcatheter aortic valve implantation: the Valve Academic Research Consortium-2 consensus document (VARC-2). Eur J Cardiothorac Surg. 2012;42(5):S45-S60.
5. Sherif MA, Abdel-Wahab M, Stocker B, et al. Anatomic and procedural predictors of paravalvular aortic regurgitation after implantation of the medtronic corevalve bioprosthesis. J Am Coll Cardiol. 2010;56(20):1623-1629.
6. Veulemans V, Maier O, Bosbach G, et al. Novel insights on outcome in horizontal aorta with self-expandable new-generation transcatheter aortic valve replacement devices. Catheter Cardiovasc Interv. 2020;96(7):1511-1519.
7. Abramowitz Y, Maeno Y, Chakravarty T, et al. Aortic angulation attenuates procedural success following self-expandable but not balloon-expandable TAVR. JACC Cardiovasc Imaging. 2016;9(8):964-972.
8. Kunkel KJ, Fiorilli P, Kobayashi T, Desai ND, Anwaruddin S, Herrmann HC. Snare-assisted valve positioning of self-expanding valves for transcatheter aortic valve replacement. JACC Case Rep. 2021;3(4):658-662.
9. Yoon SH, Kim WK, Dhoble A, et al. Bicuspid aortic valve morphology and outcomes after transcatheter aortic valve replacement. J Am Coll Cardiol. 2020;76(9):1018-1030.
10. Vincent F, Ternacle J, Denimal T, et al. Transcatheter aortic valve replacement in bicuspid aortic valve stenosis. Circulation. 2021;143(10):1043-1061.
11. Zegdi R, Ciobotaru V, Noghin M, et al. Is it reasonable to treat all calcified stenotic aortic valves with a valved stent? Results from a human anatomic study in adults. J Am Coll Cardiol. 2008;51(5):579-584.
12. Fadahunsi OO, Olowoyeye A, Ukaigwe A, et al. Incidence, predictors, and outcomes of permanent pacemaker implantation following transcatheter aortic valve replacement: analysis from the U.S. Society of Thoracic Surgeons/American College of Cardiology TVT registry. JACC Cardiovasc Interv. 2016;9(21):2189-2199.
13. Siontis GC, Juni P, Pilgrim T, et al. Predictors of permanent pacemaker implantation in patients with severe aortic stenosis undergoing TAVR: a meta-analysis. J Am Coll Cardiol. 2014;64(2):129-140.
14. Sammour Y, Krishnaswamy A, Kumar A, et al. Incidence, predictors, and implications of permanent pacemaker requirement after transcatheter aortic valve replacement. JACC Cardiovasc Interv. 2021;14(2):115-134.
15. Nai Fovino L, Cipriani A, Fabris T, et al. Anatomical predictors of pacemaker dependency after transcatheter aortic valve replacement. Circ Arrhythm Electrophysiol. 2021;14(1):e009028.
16. Mauri V, Reimann A, Stern D, et al. Predictors of permanent pacemaker implantation after transcatheter aortic valve replacement with the SAPIEN 3. JACC Cardiovasc Interv. 2016;9(21):2200-2209.
17. Muller DWM, Farivar RS, Jansz P, et al. Transcatheter mitral valve replacement for patients with symptomatic mitral regurgitation: a global feasibility trial. J Am Coll Cardiol. 2017;69(4):381-391.
18. Bapat V, Rajagopal V, Meduri C, et al. Early experience with new transcatheter mitral valve replacement. J Am Coll Cardiol. 2018;71(1):12-21.
19. Testa L, Popolo Rubbio A, Casenghi M, Pero G, Latib A, Bedogni F. Transcatheter mitral valve replacement in the transcatheter aortic valve replacement era. J Am Heart Assoc. 2019;8(22):e013352.
20. Eleid MF, Cabalka AK, Malouf JF, Sanon S, Hagler DJ, Rihal CS. Techniques and outcomes for the treatment of paravalvular leak. Circ Cardiovasc Interv. 2015;8(8):e001945.

SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

How to cite this article: O'Neill BP, Wang DD, Caranasos TG, Chitwood WR Jr., O'Neill WW, Stack R. Initial in-human experience with the conveyor cardiovascular system for the delivery of large profile transcatheter valve devices. Catheter Cardiovasc Interv. 2021;1–6. https://doi.org/10.1002/ccd.29956