

Intracardiac echocardiography utilization in early commercial transcatheter tricuspid valve replacement

Georgi K. Fram *, John Dawdy, Leo Kar Lok Lai, Hussayn Alrayes, Kartik Gupta, Mustafa Mohammed, Liyan Obeidat, Mariam Saleem, Bryan Zweig, Sachin Parikh, Pedro Engel Gonzalez, Pedro Villablanca, Tiberio Frisoli, Brian O'Neill, and James Lee

Division of Cardiology, Center for Structural Heart, Henry Ford Hospital, 2799 W. Grand Blvd, CFP-432, Detroit, MI 48202, USA

Received 27 August 2025; revised 27 October 2025; accepted after revision 19 November 2025; online publish-ahead-of-print 29 January 2026

Abstract

Background and Aims

Transcatheter tricuspid valve replacement (TTVR) is a novel treatment for patients with severe tricuspid regurgitation (TR). Procedural success hinges on intraprocedural imaging quality. Three-dimensional intracardiac echocardiography (3D-ICE) is an important adjunctive imaging modality in this setting; however, data on optimal use strategies remain limited.

Methods and results

Retrospective review of 100 patients undergoing TTVR at a single centre between February 2024 and April 2025 was conducted. 3D-ICE was employed selectively as adjunctive imaging when transoesophageal echocardiography (TEE) was sub-optimal. Baseline characteristics and procedural outcomes were analysed. 3D-ICE was used in 29 patients. Baseline characteristics were similar between groups, although patients requiring ICE had higher prevalence of cardiovascular implanted electronic devices (CIED) (52% vs. 24%, $P < .05$). Procedural duration was longer in 3D-ICE patients, (141 [IQR 123, 180] min) compared with TEE-alone, (115 [100, 138] min, $P < .05$), although this improved over time. Post-procedurally, patients requiring adjunctive 3D-ICE had more residual TR (>mild in 14% vs. 3%, $P < .05$). There was no difference in 30-day mortality (3.4% ICE vs. 5.6%, $P = .65$) or Kansas City Cardiomyopathy-Questionnaire scores at follow-up (65% ICE vs. 51%, $P = .24$).

Conclusions

This is the first large-scale report of 3D-ICE use during TTVR with EVOQUE (Edwards Lifesciences, Irvine, USA). 3D-ICE was employed when TEE was suboptimal, often in patients with CIEDs. Its use correlated with longer procedures and more residual TR, likely reflecting higher case complexity, though clinical outcomes were equal. Procedural efficiency improved over time, with no cases aborted due to imaging. Primary 3D-ICE approach may have similar procedural time without affecting safety, supporting further evaluation of up-front ICE use and focused training.

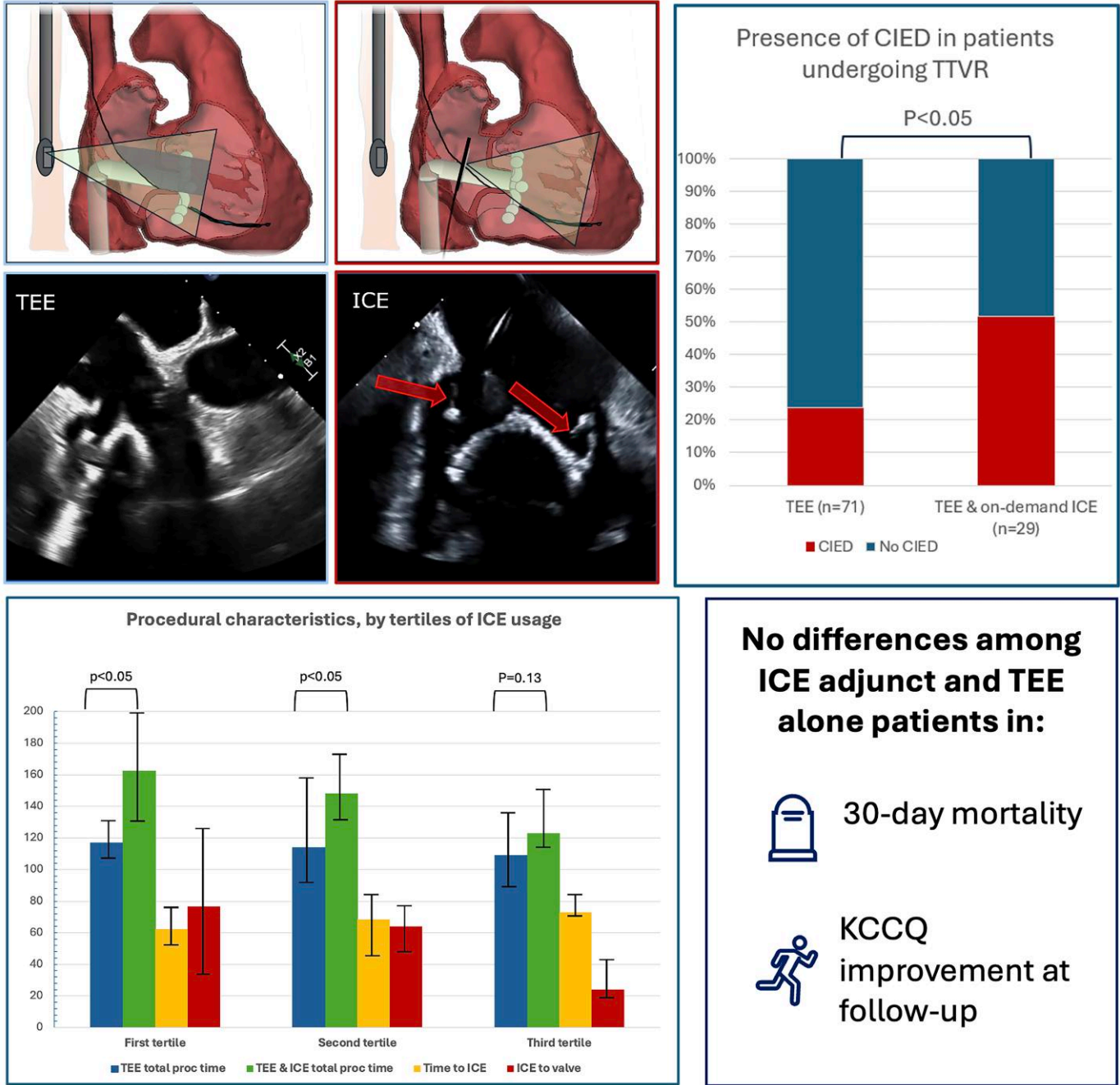
* Corresponding author. Tel: +1 313 916 2177, Email: gfram1@hfhs.org

© The Author(s) 2026. Published by Oxford University Press on behalf of the European Society of Cardiology.

This is an Open Access article distributed under the terms of the Creative Commons Attribution-NonCommercial License (<https://creativecommons.org/licenses/by-nc/4.0/>), which permits non-commercial re-use, distribution, and reproduction in any medium, provided the original work is properly cited. For commercial re-use, please contact reprints@oup.com for reprints and translation rights for reprints. All other permissions can be obtained through our RightsLink service via the Permissions link on the article page on our site—for further information please contact journals.permissions@oup.com.

Graphical Abstract

Graphical Abstract: Role of Intracardiac Echocardiography in Transcatheter Tricuspid Valve Replacement



Downloaded from https://academic.oup.com/ehj/advance-article/doi/10.1093/ehj/ehy002/8444516 by guest on 09 February 2026

Intracardiac echocardiography (ICE) is vital in the successful implantation of transcatheter tricuspid valve replacement (TTVR) among patients with poor acoustic windows on transoesophageal echocardiography (TEE), such as those seen in patients with cardiac implantable electrical devices (CIED). In our first 100 patients undergoing commercial TTVR, 29 required adjunct ICE imaging, majority of whom had CIED present. There was a significant difference in CIED presence among patients requiring adjunctive ICE imaging vs. those requiring TEE imaging alone (52% vs. 24%, *P* < .05). TTVR procedural length requiring adjunct ICE imaging improved over time, and in the final tertile of patients requiring ICE had no significant difference compared with those requiring TEE alone. There were no differences in 30-day mortality or KCCQ improvement in patients requiring adjunctive ICE imaging vs. those requiring TEE alone.

Keywords

TTVR • ICE • EVOQUE • Imaging • CIED • Transoesophageal echocardiography

Introduction

Severe tricuspid regurgitation (TR) is associated with increases in short- and long-term mortality, while being under-diagnosed.^{1–3} Surgical methods of treatment of isolated tricuspid valve surgery have shown persistent high in-hospital mortality despite increased procedure volumes, spurring interest in transcatheter replacement techniques.^{4,5} In recent years, transcatheter tricuspid interventions have rapidly advanced with recent FDA approval in the USA of the EVOQUE valve (Edwards Lifesciences, Irvine, USA) and TriClip (Abbot Laboratories, Abbott Park, USA).^{6–9}

Intraprocedural echocardiographic guidance of transcatheter tricuspid valve replacement (TTVR) with EVOQUE requires high-fidelity imaging throughout the procedure to ensure capture of the native tricuspid leaflets within all nine anchors of the EVOQUE valve.¹⁰ Imaging for TTVR is technically difficult and is typically performed with transoesophageal echocardiography (TEE) by a highly trained interventional echocardiographer facile with advanced imaging techniques such as live multi-planar reconstruction (MPR). The EVOQUE valve procedure, upon anchor exposure, is progressive and irreversible, underscoring the importance of optimal imaging and patient selection prior to deployment. The consequences of inadequate leaflet capture ranges from paravalvular leak to more catastrophic complications such as device migration.¹¹

Even with latest generation TEE probes and software, TEE is susceptible to acoustic shadowing during TTVR due to limitations of available imaging windows and the large bore delivery system. In many patients, additional challenges exist including distortion and rotation of anatomy due to right ventricular dilation and acoustic shadowing in patients with cardiac implantable electronic devices (CIED) or bioprosthetic valves in the mitral or aortic positions. Three-dimensional intracardiac echocardiography (3D-ICE) has value as an adjunctive imaging technique to aid with transcatheter tricuspid interventions in patients with challenging anatomy.¹² Successful utilization of 3D-ICE in TTVR often requires experience and specific expertise in novel techniques for image optimization.^{13,14} Despite its importance, there is a dearth in larger cohorts of patients describing and validating its use.¹⁵ Notably, there have been recent case-based protocols for combined TEE and 3D-ICE guidance for TTVR; however, data from larger series are needed to understand real-world utilization patterns and outcomes.¹⁶ To our knowledge, this is the first large scale description of real-world usage and outcomes describing 3D-ICE in TTVR with EVOQUE.

Methods

This study was a retrospective review of all patients with symptomatic TR at high surgical risk who underwent commercial TTVR with EVOQUE at a single institution between February 2024 and April 2025. Patients underwent standard of care routine pre-procedural imaging with transthoracic echocardiogram (TTE), TEE, and pre-planning cardiac computed tomography angiography to obtain complete valve sizing, regurgitation severity, mechanism of TR, and anatomical characteristics. Patient selection was performed by a multi-disciplinary discussion by a Heart Team. Anatomic suitability and valve sizing was performed via internal as well as vendor supplied analysis. Each patient had a TTE post-procedurally and was followed clinically for at least 30 days or until their scheduled follow-up. The study was approved by local Institutional Review Board.

All patients underwent general anaesthesia with TEE guidance provided by dedicated interventional imaging cardiologists. 3D-ICE was used as an 'on-demand' adjunct, jointly decided by imaging and implanting teams, and employed only when intraprocedural TEE was deemed suboptimal and additional imaging was necessary to safely complete the procedure.

Retrospective analysis was conducted on baseline patient characteristics, along with post-procedural outcomes. All patients received TTE prior to discharge from the hospital. Patients were screened with the Kansas City Cardiomyopathy Questionnaire (KCCQ) pre-procedurally and were

attempted to be contacted at least 1-month post-procedurally for follow-up assessment of quality-of-life improvement, defined as an increase in KCCQ by ≥ 10 points.

Intracardiac echocardiography

ICE imaging was performed with clinically available 3D-ICE catheters. Initial cases utilized the AcuNav linear spiral array 3D-ICE catheters (Siemens, Munich, Germany), which utilized a 14F 30 cm long sheath. Later cases utilized the VeriSight matrix array 3D-ICE catheters (Philips, Amsterdam, Netherlands), which utilized an 11F 25 cm long sheath. Imaging with ICE catheters was done primarily using live 3D MPR guidance. In cases where excessive acoustic shadowing occurred despite ICE, advanced catheter manipulation techniques were utilized as needed, such as nearfield advancement, the backbend technique,¹³ and fluoroscopy-guided navigation, which we have previously described.¹⁴

Continuous variables were represented as medians with inter-quartile ranges (IQRs) and categorical variables were represented as counts with proportions. The Wilcoxon rank-sum test and χ^2 tests were used to identify the differences in continuous and categorical variables, respectively. All statistical analyses were performed in Stata/SE version 18.0 (StataCorp®, College Station, TX, USA). All *P*-values were 2-sided with $<.05$ considered statistically significant.

Results

Patient population

Between February 2024 and April 2025, 100 patients underwent successful implantation of the EVOQUE valve. Median age (IQR) was 79 (72–84), and 70% of patients were female. There were 29 patients requiring adjunctive imaging with 'on-demand' utilization of 3D-ICE. Baseline patient characteristics are demonstrated in [Table 1](#). There was no difference in age, sex, BMI, surgical risk, history of atrial fibrillation, or end-stage renal disease between the two groups. The degree of baseline TR seen in each group was also similar, with 95% of all patients having at least moderate-severe pre-procedural TR ([Figure 1](#)).

Amongst patients requiring adjunctive 3D-ICE imaging, there was a significantly higher rate of cardiovascular implanted electronic devices (CIED), compared with those able to complete the procedure with TEE alone (15 (52%) vs. 17 (24%), $P < .05$). Though not statistically significant, adjunctive 3D-ICE patients had greater percentage of prosthetic aortic valves, 9 (31%) vs. 12 (17%), $P = .12$; and prosthetic mitral valves, 3 (10%) vs. 2 (3%), $P = .12$.

Intraprocedural ICE usage

Procedural characteristics with post-procedural outcomes are demonstrated in [Table 2](#). The overall median procedure time (IQR), defined as administration of subcutaneous lidocaine for vascular access to hemostasis, was longer in patients who required adjunctive 3D-ICE as compared with those who required TEE alone, (141 [123, 180] vs. 115 [100, 138] min, $P < .05$). However, there were no significant differences in fluoroscopy time (44 [34, 54] vs. 37 [30, 46] min, $P = .052$) or air kerma dose (440 [219, 541] vs. 338 [216, 598] mGy, $P = .52$).

On average, 3D-ICE catheters were introduced approximately 68 min (IQR 53–84) after procedure start. Following 3D-ICE deployment, the median time to valve implantation was 49 min (IQR 22–76). When analysing tertiles of patients necessitating adjunctive 3D-ICE, a trend was seen demonstrating reduced procedural time over the study period in each successive tertile. In the first and second tertile of patients requiring 3D-ICE, compared with patients who did not require adjunctive 3D-ICE imaging during the same study period, there were significantly longer procedure times overall ([Table 3](#)). However, by the third tertile of patients requiring adjunctive 3D-ICE, there was no difference in procedural time as compared with those requiring TEE alone (123 [114, 151] min vs. 109 [89, 136], $P = .13$).

Table 1 Baseline patient characteristics

	TEE alone (n = 71)	ICE and TEE (n = 29)	P-value
Age, years, median (IQR)	79 (72, 84)	79 (71, 83)	.72
Female sex, n (%)	51 (72%)	19 (66%)	.54
Body mass index, kg/m ² , median (IQR)	28 (24, 32)	27 (24, 31)	.36
STS, PROM %, median (IQR)	13.4 (7.8, 18.5)	14.8 (9.0, 27.8)	.15
Atrial fibrillation, n (%)	53 (75%)	23 (79%)	.62
ESRD, n (%)	8 (11%)	5 (17%)	.42
CIED, n (%)	17 (24%)	15 (52%)	<.05
Prosthetic aortic valve, n (%)	12 (17%)	9 (31%)	.12
Prosthetic mitral valve, n (%)	2 (3%)	3 (10%)	.12
Mitral annuloplasty, n (%)	3 (4%)	1 (3%)	.86
Mitral TEER, n (%)	10 (14%)	2 (7%)	.32
Baseline echo TR severity			.12
Severe (including massive, torrential)	56 (79%)	24 (83%)	
Moderate-severe	13 (18%)	2 (7%)	
Moderate	2 (3%)	3 (10%)	

Patients who required adjunctive ICE imaging intraoperatively had a higher rate of CIED than those who did not. There were no other significant differences, including in pre-procedural severity of TR.

TEE, transoesophageal echocardiogram; ICE, intracardiac echocardiography; STS, Society of Thoracic Surgeons; PROM, predicted risk of mortality; CIED, cardiovascular implantable electronic device; ESRD, end-stage renal disease; TEER, transcatheter edge-to-edge repair; TR, tricuspid regurgitation.

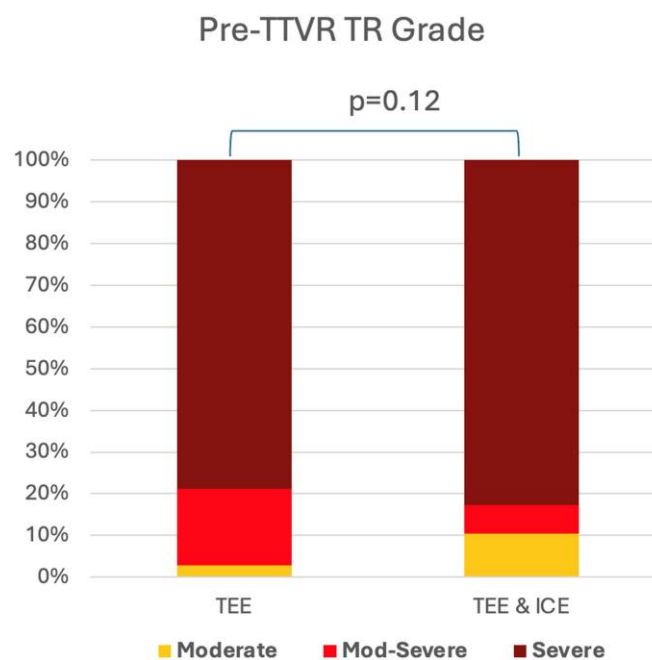


Figure 1 Pre-procedural grading of TR, as determined by echocardiography. There was no difference in pre-procedural degree of TR between both groups of patients

Table 2 Procedural characteristics and patient outcomes

	TEE alone (n = 71)	ICE and TEE (n = 29)	P-value
Procedure time, min, median (IQR)	115 (100, 138)	141 (123, 180)	<.05
Air kerma, mGy, median (IQR)	338 (216, 298)	440 (219, 541)	.52
Fluoro time, min, median (IQR)	37 (30, 46)	44 (34, 54)	.052
Procedural mortality	1	0	.54
Stroke	0	0	NA
Post-procedural echo TR severity			<.05
None/trivial	53 (76%)	16 (55%)	
Mild	15 (21%)	9 (31%)	
Mild-moderate	2 (3%)	4 (14%)	
KCCQ, $\Delta \geq +10$, n (% of respondents)	30 (51%)	15 (65%)	.24
30-day mortality, n (%)	4 (5.6%)	1 (3.4%)	.65

Procedure time was longer in patients requiring adjunctive ICE imaging.

TEE, transoesophageal echocardiogram; ICE, intracardiac echocardiography; TR, tricuspid regurgitation; KCCQ, Kansas City Cardiomyopathy Questionnaire.

Table 3 Procedural time and characteristics as divided by tertiles of ICE usage

	Total procedural time, min (IQR)			Time to ICE, min (IQR)	ICE to valve, min (IQR)
	TEE alone	ICE and TEE	P-value		
First tertile, n, total procedural time, min (IQR)	29, 117 (108, 132)	10, 162.5 (131, 199)	.008	62.5 (52, 76)	76.5 (34, 126)
Second tertile	19, 114 (91, 158)	10, 148 (130, 172)	.028	68.5 (46, 84)	64 (48, 76)
Third tertile	23, 109 (89, 136)	9, 123 (114, 151)	.13	73 (71, 84)	24 (19, 43)
				P = .34	P < .05

The numbers in italics in the columns are the total number of patients.

Initially, there were significant differences seen in procedural times between adjunctive ICE patients and patients only requiring TEE, as seen in the first two tertiles ($P < .05$). By the third tertile, there was no difference in procedural time between cases requiring adjunctive ICE imaging compared with those requiring TEE alone ($P = .13$). Additionally, there was no difference in the time from the start of the procedure to deploying ICE amongst each tertile ($P = .34$). Lastly, by the third tertile of patients, the median time from ICE deployment to was significantly less than the first two tertiles ($P < .05$). Total procedural time defined as lidocaine injection to hemostasis. Time to ICE defined as lidocaine injection to introduction of ICE catheter into the right atrium. ICE to valve defined as time from ICE deployed into the right atrium to the full release of the valve.

(Figure 2). Additionally, although there was no difference seen in time to 3D-ICE deployment across all three tertiles, defined as time from lidocaine to 3D-ICE entering the right atrium ($P = .34$), the time from ICE insertion to valve deployment did significantly reduce over time, with median time reducing to 24 (19, 43) min by the final tertile of patients ($P < .05$).

The VeriSight matrix array ICE catheter was used in 18 patients, while the AcuNav linear spiral array ICE catheter was used in 11 patients. The VeriSight ICE catheter became available later in our study, with 18 of the final 19 patients requiring adjunctive 3D-ICE. In VeriSight ICE patients, the median time from ICE insertion to valve deployment was 46 min (IQR 20–59), compared with 78 min (IQR 36–119) in the 11 patients with AcuNav ICE ($P = .06$). Over time, a trend towards shorter ICE-to-deployment intervals and decrease case time variability was observed across all ICE cases (Figure 3).

Outcomes

Amongst the entire cohort, 99 patients achieved clinical success, defined as valve deployed, with delivery system retrieved as intended.¹¹ There was one procedural mortality in a patient that required TEE imaging alone. This single mortality had successful valve deployment and was related to a complication in delivery system removal. In all 29 patients who required adjunct 3D-ICE, the EVOQUE valve was successfully deployed. With the 'on-demand' adjunct 3D-ICE approach, no cases were aborted due to inadequate imaging. Post-procedurally, there was more residual TR seen in patients requiring adjunct 3D-ICE (>mild TR 14% vs. 3%, $P < .05$) (Figure 4A). When controlling for presence of CIED, patients requiring adjunctive 3D-ICE usage had no statistically significant difference, although trended towards more residual TR (>mild 14% vs. 2%, $P = .06$) (Figure 4B).

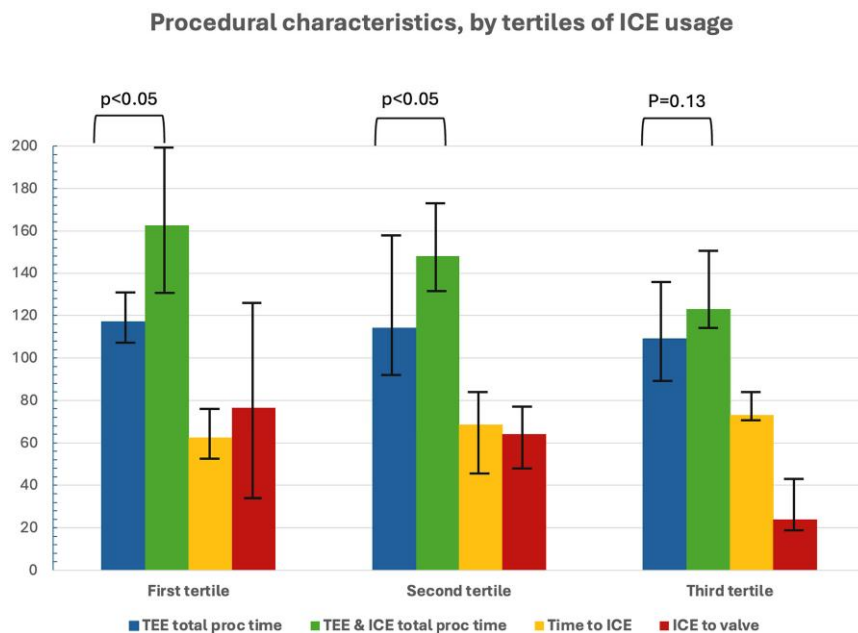


Figure 2 Procedural length, by tertiles of ICE usage. First column (blue bars) represent total procedural time for cases using TEE alone, while second column (green bars) represent total procedural time for cases requiring adjunctive 3D-ICE. Third column (orange bars) denote the time from lidocaine administration to ICE catheter insertion into the right atrium. Fourth column (red bars) represent time from ICE entering the right atrium to the release of the deployed valve. The first, second, and third tertiles correspond to the chronological first, middle, and final one-third of cases that utilized 3D-ICE during the study period. Total procedural time was initially longer with 3D-ICE ($P < .05$) but became comparable to TEE-alone cases by the third tertile ($P = .13$). While total procedural time decreased, this was driven by reduction in time from ICE deployment to release of valve, while time to ICE opening remained similar throughout the study period

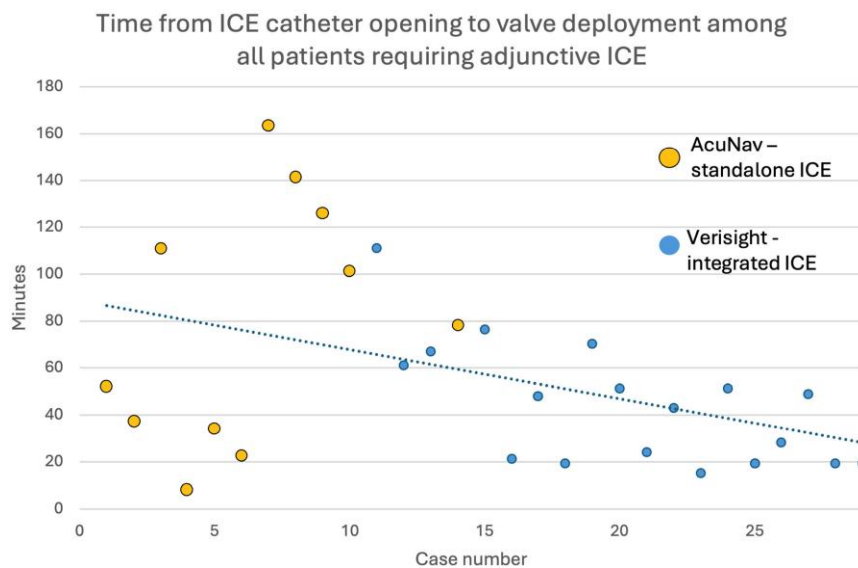


Figure 3 Length of time from ICE catheter opening to valve deployment. Over time, and with usage of latest generation integrated system ICE catheters, time to valve deployment was reduced after opening of ICE catheter. The matrix array ICE catheter became available later in our experience, and was used more often after its introduction

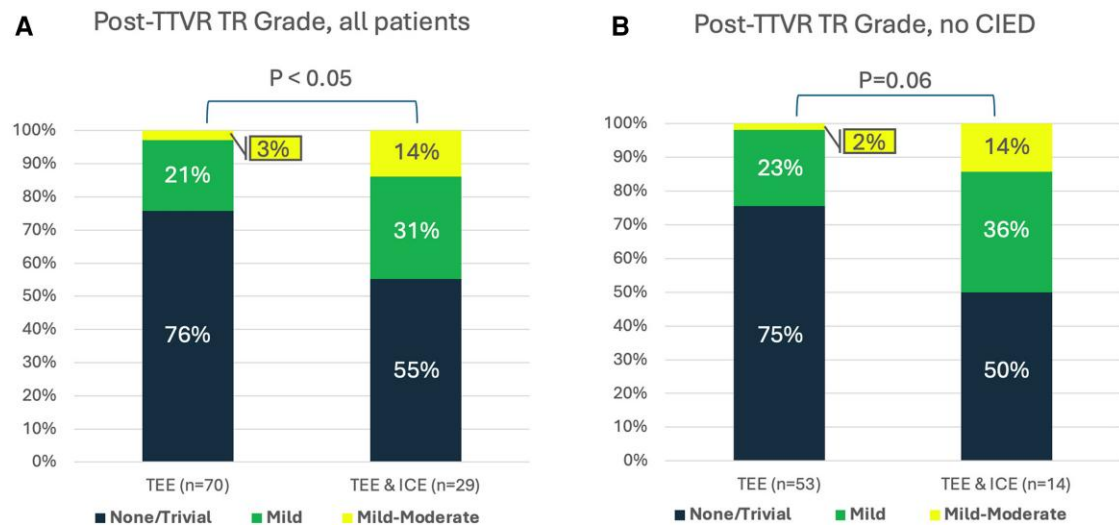


Figure 4 A) Post-procedural grading of TR amongst all patients, as determined by echocardiography. Patients requiring ICE adjunctive on-demand imaging had more residual TR compared with those only needing TEE. There was one intraprocedural mortality in the TEE arm. B) Post-procedural grading of TR in patients without CIED, as determined by echocardiography. Although a trend was present, there was no significant difference in post-procedural TR when controlling for CIED presence

There were no other significant differences in outcomes, including improvement in KCCQ scores at follow-up (ICE 65% vs. TEE 51%, $P = .14$), and in 30-day mortality between the two groups (ICE 3% vs. TEE 6%, $P = .65$).

Discussion

TTVR with EVOQUE has rapidly expanded in utilization following its commercial availability with CE Mark approval in the European Union, and FDA approval in the USA. The progressive and irreversible steps of the procedure render patient selection and effective intra-procedural imaging of the utmost importance to procedural success. In institutions with experience performing transcatheter tricuspid procedures such as tricuspid edge-to-edge repair, 3D-ICE is commonly used.^{17,18} While TEE remains the cornerstone of TTVR for the foreseeable future, we believe that our experience highlights that centres performing TTVR with EVOQUE should have access to high quality, latest generation 3D-ICE catheters as an essential component of a successful programme. Our study demonstrates that a combination of 3D-ICE technology, integrated systems, and experience of operators and imagers are critical to ensure that even highly complex patients with sub-optimal acoustic windows, can demonstrate procedural success with an adjunct ICE workflow.

In our study, however, patients who necessitated adjunctive 3D-ICE had longer procedural times in early experience. This is likely explained by our 'on-demand' approach towards ICE catheter utilization where ICE was only deployed at the point when TEE imaging was no longer felt sufficient for the safe completion of the procedure. The absence of a significant difference of fluoroscopy time and air kerma is suggestive that echocardiographic imaging limitations were a significant contributor to longer case times. As the study progressed however, the difference in total procedural times continued to shrink between the two groups, and by the third tertile of ICE patients, there was no significant difference between ICE and TEE alone during the same study period. This may be due to a combination of experience with TTVR, in addition

to greater expertise with ICE. The time to ICE deployment did not differ, while the time from ICE to valve release significantly reduced in subsequent tertiles, demonstrating with increased experience came improved procedural efficiency.

Additionally, the integrated matrix array 3D-ICE system was not introduced until later in our study. This may have offered additional benefit in reduction of procedural length over time, vs. the linear spiral stand-alone 3D-ICE system. Our echocardiogram carts used for intra-procedural TEE were able to integrate with the matrix array ICE system, allowing for a streamlined user interface with interventional echocardiographer control of software navigation. With the integrated matrix array ICE system, there was minimal interruption after ICE was deployed to swap between TEE and ICE, allowing for rapid switching between the modalities as needed.

3D-ICE was utilized more in patients with CIED leads; possibly reflecting more difficult imaging in these patients. CIED leads often cause shadowing of native tricuspid leaflets, leaving TEE susceptible to acoustic artefacts during the procedure, making it challenging to visualize if the native leaflets are captured within the anchors of the EVOQUE valve. ICE may be able to overcome these limitations due to its capacity for precise maneuverability around leads and its ability to obtain imaging in closer proximity to the tricuspid annular plane as compared with TEE. While there are validated scoring systems available to predict case complexity in tricuspid valve transcatheter edge-to-edge repair, no such score is available for TTVR.¹⁹ Our cohort of patients demonstrates that factors such as presence of CIED may in fact predict higher case complexity and highlights the need for further studies.

In our study, patients requiring 'on-demand' adjunctive 3D-ICE exhibited a greater degree of post-procedural TR. Although this difference was not statistically significant after adjusting for the presence of CIED leads, a trend towards increased residual TR persisted in this cohort. The reason for this remains uncertain; however, these findings may be hypothesis-generating. Specifically, the 'on-demand' ICE approach—initiated only after encountering difficulty with anatomic visualization—may have resulted in delayed identification of technical challenges, at which point corrective maneuvers are more limited

due to device constraints and the inability to retract prior expansion of the valve. Notably, despite the higher prevalence of residual TR in patients requiring ICE, there were no significant differences in short-term clinical outcomes, including 30-day mortality and improvement in KCCQ scores.

This observation of higher residual TR in patients requiring on-demand adjunctive 3D-ICE leads to the question of whether usage of an 'up-front' 3D-ICE strategy, with utilization of 3D-ICE from the start of the procedure, may reduce the rate at which this occurs in patients with known risk factors for challenging imaging, such as presence of CIED leads. There are, however, drawbacks with increased ICE utilization, namely the necessity for additional large-bore venous access, and higher cost associated with single-use 3D-ICE probes. This discussion is likely to continue to evolve given increasing interest in extraction of CIED leads prior to planned-TTVR.²⁰

Future directions

Recently published data have evaluated a primary 3D-ICE strategy for tricuspid interventions, including TTVR, demonstrating shorter procedural times without compromise in patient safety or efficacy.²¹ These findings support the potential benefit of a planned up-front ICE approach in select cases, aligning with our observation that on-demand ICE use is safe and feasible, and warrants prospective evaluation in larger studies.

Although latest generation 3D-ICE catheters have shown substantial improvement over earlier devices, further work is needed to continue enhancement of spatial and temporal resolution in 2D, 3D, and MPR imaging. The improvement in image quality seen with newer-generation 3D-ICE catheters results primarily from hardware and software enhancements in signal processing and image reconstruction. The major limitation of the current generation of 3D-ICE catheters is the comparatively weak spatial resolution due to its smaller physical transducer array vs. TEE. While the imaging quality is highest at 0 degrees on 3D-ICE, where the aperture is largest parallel to the catheter, the relatively small number of imaging elements in the 90-degree plane have substantially less optimal image quality. This can often be surmounted by advanced techniques that require close co-ordination and collaboration by the interventional echocardiographer and interventional cardiology implanters. Continued advances in these technologies may offer additional benefit, such as reduced pre-procedural imaging in patients with challenging acoustic windows with the reassurance of higher quality intraprocedural imaging which may be provided by 3D-ICE. This is particularly relevant given the increased risk associated with outpatient diagnostic TEE studies in patients with TR as compared with historical TEE patients.²²

Another hindrance of wider spread adoption of 3D-ICE is the associated high cost towards the healthcare system. 3D-ICE catheters are expensive to manufacture and are currently designed as single-use disposable devices, although early feasibility studies have shown promise towards the sterilization and re-usage of ICE catheters.²³ Widespread adoption and standardization of these processes may allow for drastic cost savings in the future. However, even with reprocessing, current reimbursement of the TEE for interventional echocardiographers remains a fraction of the cost of a single 3D-ICE catheter. Furthermore, interventional echocardiographers could spend the entirety of a multi-hour case providing imaging support for a TTVR case, but this time is currently not billable.

Limitations

There are several limitations with our study. This is a single-centre, retrospective analysis which is describing early experience with 3D-ICE utilization in TTVR with short-term clinical outcomes. There is no established protocol currently to guide 3D-ICE imaging in

TTVR and utility of ICE in this study was at the discretion of the structural physicians intraprocedurally leading to some heterogeneity of cases. The generalizability of this may be limited to other high-volume centres with dedicated structural imagers.

Finally, although there was a reduction in imaging time from the use of ICE to procedure completion over the study period, it is difficult to determine whether this was due to differences in technology used and/or increased experience with both the EVOQUE device and ICE techniques by the interventional echocardiographer and interventional cardiology implanting team. Larger, prospective studies with longer follow-up are needed to determine if different approaches reduce TR in patients requiring ICE, such as usage of adjunctive ICE imaging up-front in higher-risk patients such as those with pre-existing CIED leads.

Conclusion

This study is the first large scale, real-world report evaluating the use of 3D-ICE in TTVR with EVOQUE. With the availability of 3D-ICE, no cases were aborted due to suboptimal image quality. Short-term clinical outcomes in cases with ICE utilization were similar to those which did not necessitate ICE, although procedures requiring ICE utilization in an 'on-demand' adjunct fashion were longer and had greater degrees of post-procedural residual TR. This suggests that there may be cohorts of patients, such as those with CIED leads, in which an 'up-front' 3D-ICE strategy could deliver benefits of improved procedural time and better outcomes; although this requires further study.

As the study period progressed, procedural times in patients requiring adjunctive ICE did not differ from patients only requiring TEE imaging, possibly reflecting greater expertise in the procedure and technical ICE strategies. Our institutional experience from this cohort has led to a lower threshold for anticipated use of 3D-ICE use in select cases. Specifically, in patients with pre-existing CIED, left-sided prosthetic valve devices, or suboptimal acoustic windows based on screening TEE. 3D-ICE catheter utilization is a distinct skillset for both interventional echocardiographers as well as interventional cardiology device implanters, and specific educational efforts may help improve adoption and could augment procedural success.

Acknowledgements

The authors would like to acknowledge James Alter and Kevin Lai for their contributions to the production of this manuscript.

Author contributions

Georgi K. Fram (Conceptualization [equal], Data curation [lead], Formal analysis [equal], Writing—original draft [lead], Writing—review & editing [lead]), John Dawdy (Investigation [equal], Writing—review & editing [equal]), Leo Kar Lok Lai (Investigation [equal]), Hussayn Alrayes (Investigation [equal]), Kartik Gupta (Formal analysis [equal], Writing—review & editing [equal]), Mustafa Mohammed (Data curation [equal]), Liyan Obeidat (Data curation [equal]), Mariam Saleem (Data curation [equal]), Bryan Zweig (Investigation [equal]), Sachin Parikh (Investigation [equal], Writing—review & editing [equal]), Pedro Engel Gonzalez (Investigation [equal]), Pedro Villablanca (Investigation [equal]), Tiberio Frisoli (Investigation [equal]), Brian O'Neill (Conceptualization [equal], Investigation [equal]), and James Lee (Conceptualization [equal], Investigation [equal], Writing—original draft [supporting], Writing—review & editing [equal]).

Declarations

Data availability

Data is available on request.

