

## RESEARCH

# Comparison of transesophageal and transthoracic echocardiography under moderate sedation for guiding transcatheter aortic valve replacement

Ines Sherifi MD<sup>1,2,\*</sup>, Alaa Mabrouk Salem Omar MD PhD<sup>2,3,4,\*</sup>, Mithun Varghese MD<sup>2</sup>, Menachem Weiner MD<sup>5</sup>, Ani Anyanwu MD<sup>6</sup>, Jason C Kovacic MD PhD<sup>2</sup>, Samin Sharma MD<sup>2</sup>, Annapoorna Kini MD<sup>2</sup> and Partho P Sengupta MD<sup>2,7</sup>

<sup>1</sup>Division of Cardiology, Weill Cornell Medical Center, New York, New York, USA

<sup>2</sup>Division of Cardiology, Mount Sinai Hospital and Icahn School of Medicine at Mount Sinai, New York, New York, USA

<sup>3</sup>Department of Internal Medicine, Bronx Lebanon Hospital Center, New York, New York, USA

<sup>4</sup>Department of Internal Medicine, Medical Division, National Research Center, Cairo, Egypt

<sup>5</sup>Division of Anesthesia, Mount Sinai Hospital and Icahn School of Medicine at Mount Sinai, New York, New York, USA

<sup>6</sup>Division of Cardiothoracic Surgery, Mount Sinai Hospital and Icahn School of Medicine at Mount Sinai, New York, New York, USA

<sup>7</sup>WVU Heart & Vascular Institute, University of West Virginia, Morgantown, West Virginia, USA

Correspondence should be addressed to P P Sengupta: [partho.sengupta@hsc.wvu.edu](mailto:partho.sengupta@hsc.wvu.edu)

\*(I Sherifi and A M S Omar contributed equally to this work)

## Abstract

The optimal periprocedural imaging strategy during transcatheter aortic valve replacement (TAVR) performed under moderate sedation is debated. Transthoracic echocardiography (TTE) provides suboptimal views due to poorer resolution and patient positioning, whereas use of transesophageal echocardiography (TEE) under moderate sedation is not widely utilized. The aim of our study was to compare the value of TTE in comparison with TEE guidance under moderate sedation during TAVR. The study population included 144 consecutive patients (mean age  $83 \pm 11$  years, 78 (54%) females) who had TAVR under moderate sedation using either a TTE ( $n=96$ ) or TEE ( $n=48$ ). We compared procedural outcomes using propensity score matching. There were no significant inter-group differences in age, sex, ejection fraction, aortic valve area, pressure gradients, creatinine or type of valve used. The procedural time was significantly shorter in the TEE group ( $P < 0.001$ ) and associated with a lower need for periprocedural aortograms ( $7.7 \pm 1.9$  vs  $8.2 \pm 1.9$ ,  $P = 0.022$ ) and a lower occurrence of acute kidney injury (1 vs 11,  $P = 0.047$ ). The 1:1 propensity score matching also showed a lower procedural time ( $P = 0.032$ ), number of aortograms ( $P = 0.014$ ) and a trend toward lower acute kidney injury in the TEE group ( $P = 0.077$ ). TAVR guidance using TEE is associated with a lower fluoroscopic time, a lower need for additional aortograms and trend in lower occurrence of post-TAVR acute kidney injury.

## Key Words

- ▶ transcatheter aortic valve replacement
- ▶ transesophageal echocardiography
- ▶ aortic stenosis
- ▶ transthoracic echocardiography

## Introduction

Transcatheter aortic valve replacement (TAVR) represents a less invasive alternative to surgical aortic valve replacement (SAVR) in high-risk symptomatic patients with severe aortic stenosis (1, 2, 3, 4). The role of periprocedural transesophageal echocardiography (TEE) in patients undergoing TAVR is valuable for confirming annular size, guiding procedural steps and for early and precise determination of hemodynamic outcomes and periprocedural complications (5). In contrast to TEE, the use of transthoracic echocardiography (TTE) periprocedurally during TAVR is cumbersome for optimal decision making because of limited image quality due to supine positioning, suboptimal imaging of the aortic root and ascending aorta for early detection of complications and the presence of the C-arm, which obviates continuous visualization. Additionally, periprocedural TTE views aimed at assisting the interventionalist during the procedure may expose the imaging operator to increased radiation (6, 7). Intraprocedural TEE is undertaken in many centers with the use of general anesthesia (GA) and endotracheal intubation (ET), which may be associated with increased anesthesia times and longer post-TAVR recovery period (8, 9, 10). An alternative strategy is the use of goal-oriented TEE undertaken under monitored anesthesia care (MAC) to provide sedation and analgesia without ET and GA (10). The first human case description of a percutaneous aortic valve implantation was undertaken with mild sedation, local anesthesia and TEE imaging undertaken within 30 min post procedure (11). Guidelines for conscious sedation are utilized in numerous echocardiography laboratories, and we and other studies have shown that the TAVR procedure performed under MAC is associated with earlier recovery, shorter procedure times and shorter hospital stay (12, 13, 14). There is currently a trend in TAVR procedures to undertake a 'minimalist approach' in order to reduce patient length of stay and hospital costs (15). However, there is limited information on the feasibility and benefits of using TEE during TAVR under MAC. In the present study, we hypothesized that the use of goal-oriented continuous TEE under MAC provides superior periprocedural guidance, which can reduce procedure time and the need for repeated aortograms in comparison with discontinuous TTE guidance during TAVR procedures.

## Methods

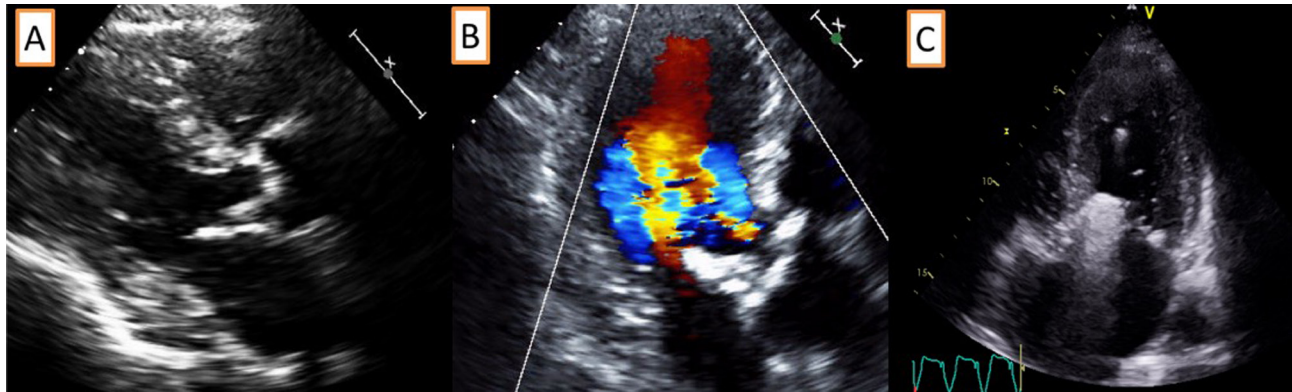
We retrospectively analyzed 144 consecutive patients who underwent TAVR under MAC between September 2012

and October 2015 for whom clinical, procedural, imaging and outcome data were assessed. The study was approved by the local ethics committee of the institution.

The TAVR procedure was undertaken with surgical backup via a transfemoral approach using either the CoreValve or Edward Sapiens Valves. All TAVR patients underwent cardiac and abdominal CT evaluations prior to the procedure in order to aid in device size selection. Fluoroscopy was used in all cases in order to guide prosthetic valve insertion. An aortogram was undertaken after valve deployment in order to assess aortic regurgitation (AR) post placement and post percutaneous valve dilatation. The following periprocedural data were collected for all patients and were compared between groups: the total procedure time, post-procedural total ICU time, post-procedural length of stay in hospital and in-hospital death.

The TAVR procedure was undertaken with either TTE or TEE. The decision for TTE or TEE was based upon the presence of an attending anesthesiologist during TAVR who had familiarity, comfort and expertise in managing MAC with TEE. Images were acquired using a Vivid 9 imaging platform (GE-Vingmed, Horton, Norway) and Arietta 60 imaging platform (Hitachi Aloka, Tokyo, Japan). All imaging procedures were performed according to the guidelines of the American Society of Echocardiography (ASE). During the echocardiographic guidance, digital routine gray-scale 2D and pulsed-wave Doppler echocardiography were recorded to assess myocardial function, periaortic structures and valve geometry (Fig. 1). Paravalvular AR (PAR) was distinguished from central AR. Central AR was quantified by incorporating the vena contracta width and jet height based on the American College of Cardiology/American Heart Association valvular guidelines (16). PAR was evaluated using the parameters proposed in the Valve Academic Research Consortium-2 (VARC-2) recommendations and categorized as absent/none, trace, mild, moderate and severe, based on the Unifying Grading Scheme Proposal (17). Valvular insufficiencies were graded according to ASE/European Association of Cardiovascular Imaging (EACVI) guideline recommendations (18).

All outcome data and in-hospital complications were collected in accordance with the transcatheter valve therapy registry guidelines and codes including the in-hospital occurrence of cardiac complications, bleeding, arrhythmia, structural complications and device success. Acute kidney injury (AKI) was also assessed in both groups as defined in the VARC-2 criteria (19, 20). Stage 1 AKI was defined as a 1.5–1.99 increase compared to baseline,



**Figure 1**

TTE images undertaken during TAVR periprocedural guidance (A and B). Parasternal long axis views and apical views of the aortic valve. (C) Limited assessment of the aortic root shown. TAVR, transcatheter aortic valve replacement; TTE, transthoracic echocardiography.

stage 2 was defined as 2–2.99 increase compared with baseline and stage 3 as a three-fold increase compared with baseline or creatinine (Cr) >4 mg/dL or dialysis (19, 20).

Categorical variables are expressed as number (%) and were compared using  $\chi^2$  test or Fisher's exact test. Continuous variables are expressed as mean  $\pm$  s.d. (median  $\pm$  s.e.) and were compared using the unpaired Student *t*-test if the variables were normally distributed and Mann–Whitney *U* test if the variables were not normally distributed. Distribution normality was checked using the Kolmogorov–Smirnov test. In order to overcome the differences between the TEE and the TTE groups in terms of baseline clinical and demographic characteristics, a 1:1 propensity score matching analysis was additionally undertaken. The propensity score was calculated using a logistic regression analysis with the dependent variable being the type of imaging procedure and the independent covariates being the following baseline clinical and demographic variables: age, gender, BMI, diabetes, hypertension and presence of chronic lung disease. A 1:1 propensity score matching was undertaken using the nearest neighbor classification with the Euclidean measure of distance. All analyses were performed with a commercially available software (SPSS version 21.0; SPSS) A *P* value of <0.05 was considered statistically significant.

## Results

The study included 144 patients who underwent TAVR (48 patients had TEE periprocedural guidance and 96 patients had TTE guided procedures). Table 1 summarizes the baseline demographic and clinical data in both study groups. There was no statistically significant difference

between patients who underwent TEE- and TTE-guided TAVRs with regard to age, sex, BMI, Society of Thoracic Surgery (STS) risk score, diabetes, hypertension, chronic lung disease, prior ischemic heart disease, stroke or peripheral arterial disease (Table 1).

Table 2 summarizes the comparison between both groups with regard to procedural parameters. Device success was found in all cases but one (47 (98%)) in the TEE group and in 90 cases (94%) in the TTE group ( $P=0.273$ ). It was found that the total procedure time was significantly lower in the TEE vs TTE-guided TAVRs expressed as mean  $\pm$  s.d. (median  $\pm$  s.e.), (136.6  $\pm$  66.2 (118  $\pm$  9.5) vs 151.1  $\pm$  40.5 (142  $\pm$  4.1) min,  $P<0.001$ , Table 2). In addition, the TEE-guided procedures showed a significantly lower fluoroscopy time (20.4  $\pm$  9.2 (21  $\pm$  0.8) vs 22.5  $\pm$  7.8 (18  $\pm$  1.3) min,  $P=0.021$ ), and lower number of aortograms per procedure (7.7  $\pm$  1.9 (7  $\pm$  0.3) vs 8.2  $\pm$  1.9 (8  $\pm$  0.2),  $P=0.022$ ). However, there was no significant difference between the groups with regard to length of stay in hospital (5.0  $\pm$  2.9 (4  $\pm$  0.3), 6.33  $\pm$  8.7 (4  $\pm$  1.26) days,  $P=0.173$ , Table 2) or the post-procedural time of stay in the ICU (67.2  $\pm$  30 (66  $\pm$  3.1) vs 88.9  $\pm$  104.6 (50  $\pm$  15.1) hours,  $P=0.927$ , Table 2). Moreover, there was no statistical difference between both groups with regard to post-TAVR AR (0 (0%) vs 5 (5%),  $P=0.127$ , Table 2). The analysis also showed that there was less occurrence of AKI post TAVR in the TEE group (1 (2%) vs 11 (23%),  $P=0.047$ ). Periprocedurally, there were three TAVR-related complications in the TEE group that were detected early and managed successfully. This included a case of aortic annular hematoma that was detected, and the patient survived after undergoing surgical repair (Fig. 2), ascending aorta dissection which underwent subsequent open surgical repair and a case of device migration

**Table 1** Baseline clinical and echocardiographic characteristics.

Characteristic	TEE (n=48)	TTE (n=96)	P value
Age (years)	83.8±8.3 (85±1.19)	83.0±11.7 (84.8±1.2)	0.673
Female sex (no. (%))	24 (50)	54 (56)	0.478
STS score	8.2±6.7 (6.6±0.97)	7.9±4.6 (6.8±0.46)	0.738
BMI (kg/m <sup>2</sup> )	26.5±5.4 (26.2±0.79)	27.1±6.1 (26.4±4.5)	0.443
Diabetes (no. (%))	19 (40)	29 (30)	0.260
Hypertension (no. (%))	48 (100)	93 (97)	0.216
Chronic lung disease (no. (%))			0.674
None	27 (56)	54 (56)	
Mild	8 (17)	11 (11)	
Moderate	8 (17)	15 (16)	
Severe	5 (10)	16 (17)	
Prior myocardial infarction (no. (%))	1 (2)	8 (8)	0.144
Prior atrial fibrillation/flutter (no. (%))	7 (15)	22 (23)	0.240
Cerebrovascular disease (no. (%))			
Prior stroke	3 (6)	8 (8)	0.657
Prior TIA	3 (6)	5 (5)	0.797
Peripheral vascular disease (no. (%))	8 (17)	11 (11)	0.425
Pre-procedural creatinine (mg/dL)	1.4±1.1 (1.1±0.16)	1.3±0.84 (1.1±0.1)	0.537
Pre-procedural creatinine >2 (mg/dL) (no. (%))	6 (13)	6 (6)	0.201
FEV <sub>1</sub>	81.9±19.1 (84±2.8)	80±26.7 (79.5±2.8)	0.503
Prior CABG (no. (%))	8 (17)	20 (21)	0.551
Echocardiographic findings			
Aortic valve area (cm <sup>2</sup> )	0.7±0.1 (0.7±0.02)	0.7±0.1 (0.68±0.01)	0.112
Mean aortic valve gradient (mmHg)	41±14 (42±1.8)	43±12 (42±1.2)	0.283
Mean LVEF (%)	61±14 (65±2.1)	57.6±13 (61±1.35)	0.051*
Moderate or severe MR (no. (%))	6 (13)	14 (15)	0.733
AS subtypes (no. (%))			
NF/NG	25 (52)	58 (60)	0.492
NF/LG	15 (31)	12 (13)	0.004
LF/NG	3 (6)	13 (14)	0.189
LF/LG	4 (8)	13 (14)	0.362

Continuous variables are expressed as mean±s.d. (median±s.e.).

\*Comparison was made by Mann–Whitney *U* test as parameters were not normally distributed.

CABG, coronary artery bypass grafting; FEV<sub>1</sub>, forced expiratory volume in one second; LF, low flow; LG, low gradient; LVEF, left ventricular ejection fraction; MR, mitral regurgitation; NF, normal flow; NG, normal gradient; TEE, transesophageal echocardiography; TIA, transient ischemic attack; TTE, transthoracic echocardiography.

that was snared into the descending aorta and treated with a second valve. In one additional case, the use of intraprocedural TEE allowed improved visualization of a large amount of calcium deposit on the aortic annulus (Fig. 3); thus, pre-deployment balloon dilatation was interrupted as soon as the calcific spur from aortic leaflet tissue was seen to indent the aortic and left atrial wall. This was in contrast to TTE use periprocedurally, which often provided limited assessment of the aortic root. There was another case of aortic root hematoma that was detected during TEE immediately after valve deployment (Fig. 2). This patient also had severe paravalvular regurgitation. The root hematoma was not identified on angiography and the TEE information avoided post valve deployment balloon dilatation. The patient was sent for emergent surgery. A calcific valve spicule was identified at surgery to have caused a aortic root hematoma.

The valve and aortic root was surgically repaired and the patient recovered completely following surgery. There was one case of a pericardial effusion and tamponade that occurred in a patient in the TTE group and was only detected on the second day after the TAVR procedure. The transvenous pacing wire had perforated through the right ventricular wall and was not detected during the TTE performed during the procedure. On the second day when the transvenous pacing wire was removed, the patient developed tamponade and required emergent pericardiocentesis and pericardial drain placement.

A 1:1 propensity score matching analysis resulted in the matching of 39 cases in each group. Comparisons were rechecked for these cases and can be found summarized in Table 3. It was found that the favorable differences in the TEE group persisted with regard to the total procedural time and the aortograms but not for post-procedural AKI



**Table 2** Procedural data.

Procedural data	TEE (n=48)	TTE (n=96)	P value
Total procedure time (min)	136.6±66.2 (118±9.5)	151.1±40.5 (142±4.1)	<0.001*
Length of stay in hospital (days)	5.0±2.9 (4±0.3)	6.33±8.7 (4±1.26)	0.173*
ICU stay (h)	67.2±30 (66±3.1)	88.9±104.6 (50±15.1)	0.927*
Fluoroscopy time (min)	20.4±9.2 (21±0.8)	22.5±7.8 (18±1.3)	0.021*
Change in creatinine (mg/dL)	-0.13±0.35 (-0.1±0.05)	0.002±0.74 (-0.04±0.08)	0.045*
AKI occurrence (no. (%))	1 (2)	11 (11)	0.047
Aortograms (no.)	7.7±1.9 (7±0.3)	8.2±1.9 (8±0.2)	0.022*
Post-TAVR AR (significant) (no. (%))	0 (0)	5 (5)	0.127
Device success (no. (%))	47 (98)	90 (94)	0.273

Continuous variables are expressed as mean±s.d. (median±s.e.).

\*Comparison was made by Man–Whitney *U* test as parameters were not normally distributed, AKI occurrence as per VARC-2 criteria.

AKI, acute kidney injury; ICU, intensive care unit; TAVR, transcatheter aortic valve replacement; TEE, transesophageal echocardiography; TTE, transthoracic echocardiography.

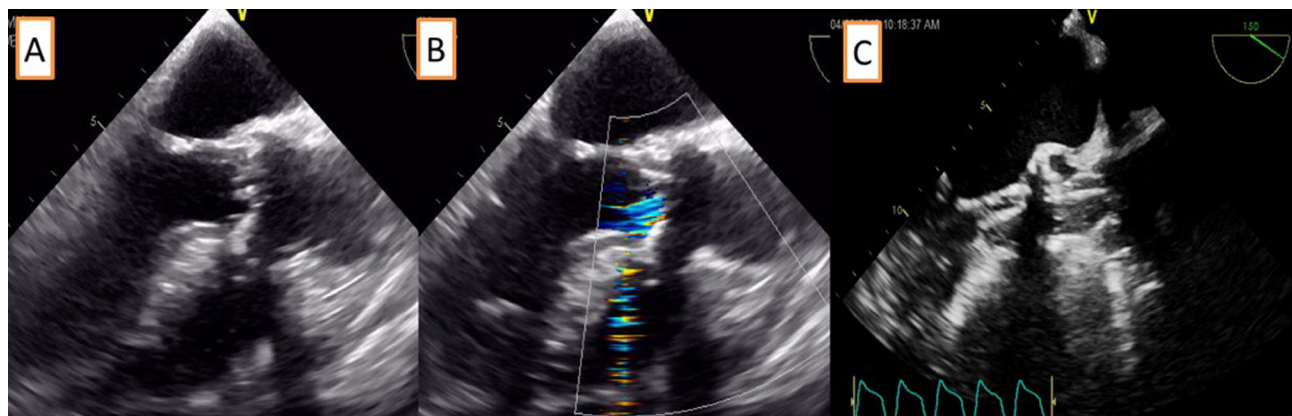
( $P=0.077$ ). A total of four cases of TIA or stroke noted in the TEE group compared to 0 cases in the TTE group ( $P=0.011$ ) (Table 4). This difference was also not seen after propensity score matching analysis ( $P=0.240$ ).

## Discussion

We retrospectively compared the use of TTE guidance during TAVR with goal-directed TEE in two patient subgroups. All cases in our study were undertaken with MAC thus avoiding the need for GA and the adverse effects of intubation and deep sedation. In order to reduce selection bias, we undertook 1:1 propensity score matching accounting for baseline and clinical variables as the independent covariates and using the nearest neighbor classification. Our study suggests that TEE guidance during TAVR is associated with reduced fluoroscopic time,

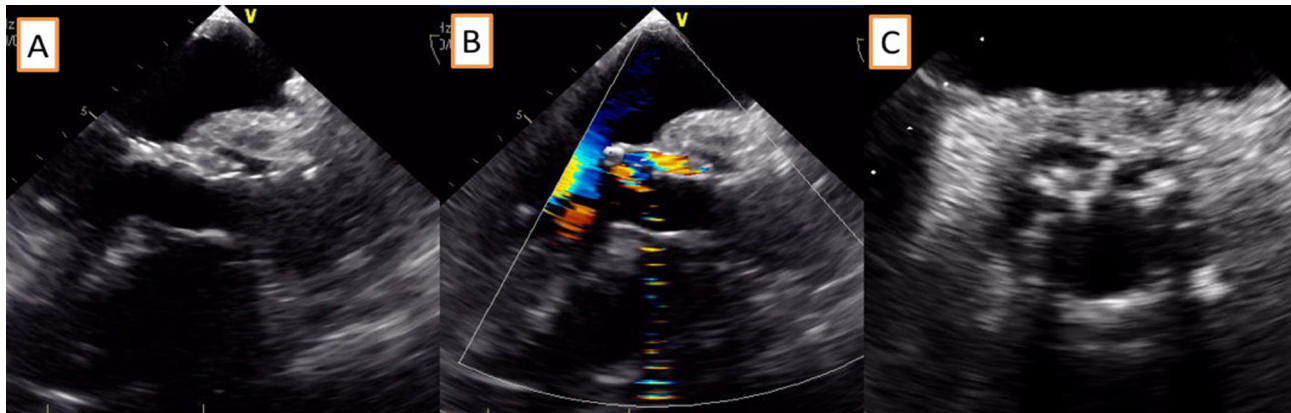
lower need for additional aortograms and was associated with less procedural AKI.

TAVR procedures have improved the management of patients with severe AS, particularly patients at extreme or high risk from SAVR. Questions remain with regard to the optimal periprocedural imaging modality used during the TAVR procedure. Proponents of using routine TEE during TAVR have cited the use of TEE in the PARTNER trial where pooled 30-day mortality rates were significantly lower than multicenter registries (3.8 vs 9.2%) (21). In addition, the use of TEE monitoring was found to be a protective factor against both early and late mortality in a Brazilian multicenter registry of 18 centers (22). One of the central arguments against the use of TEE during TAVR is the need for GA during the TEE procedure. In this regard, TEEs with moderate sedation, which are successfully performed in clinical practice for procedures like percutaneous balloon mitral commissurotomy could be adapted to TAVR and



**Figure 2**

Post-TAVR aortic trauma diagnosed by TEE under MAC. TEE showing aortic root hematoma with moderate paravalvular regurgitation in an 80-year-old patient peri-TAVR procedure (A, B and C). The patient was taken urgently to the operating room for open repair and was successfully discharged home post recovery. MAC monitored anesthesia care; TAVR, transcatheter aortic valve replacement; TEE, transesophageal echocardiography.



**Figure 3**

TEE images undertaken during TAVR periprocedural guidance (A and B). Improved visualization of the left ventricular outflow tract, aortic root and aortic valve shown with TEE. (C) Large amount of calcium seen in the aortic annulus. In this case, pre-deployment balloon dilatation was averted due to the amount of calcium. TAVR, transcatheter aortic valve replacement; TEE, transesophageal echocardiography.

may have advantages in optimizing procedural guidance (23, 24, 25, 26, 27).

The occurrence of renal failure in TAVR is multifactorial and can be related to iodinated contrast, hypotension during rapid pacing and calcific or atheromatous embolization to the kidneys intra-procedurally (28). Other predictors of AKI post TAVR include periprocedural life-threatening bleeding, hypertension and chronic obstructive pulmonary disease (29, 30). A study assessing the occurrence of AKI in 386 post-TAVR patients as defined by VARC-2 criteria revealed that AKI occurs in as high as 27.5% (22% in stage 1, 1.6% in stage 2 and 3.9% in stage 3) (31). Of these, 7 (1.2%) patients needed chronic renal replacement therapy at 6 months (31). Given the high occurrence of AKI post TAVR, there is a need for optimization of patients with chronic renal insufficiency as well as optimization of the procedure to limit renal injury. Previous studies have compared the use of TEE vs fluoroscopy alone during TAVR and have found a significant reduction in the amount of contrast used periprocedurally in the TEE group (30). Ferrari *et al.* report a series of 30 consecutive patients undergoing transapical

TAVR implantation without angiography and with the use of TEE alone (32).

Our analysis also showed that there was a trend in higher AKI with the TTE procedure compared to TEE guidance. This trend was associated with a statistically significant increased use of aortograms in the TTE group ( $P=0.014$ ). This is in keeping with previous studies that have shown a significant decrease in the amount of contrast during TAVR when using TEE vs fluoroscopy (12 (5–20) mL vs 40 (20–50) mL,  $P<0.0001$ ); however, to our knowledge, this is the first direct comparison of TEE and TTE guidance (33).

An important concern during TAVR procedures is the radiation exposure to the patient and medical personnel. The exposure dose increases with fluoroscopy time and shorter distance to the Xray beam. An operator undertaking a TTE intraprocedurally on the left side of the patient close to the Xray tube may be exposed to significantly higher radiation. The amount of scatter radiation from a lateral C-arm can be as high as four times greater on the side where the Xray tube is located (7). Additionally, TTE imaging may require the hand of

**Table 3** Propensity score matching analysis.

Procedural data	TEE (n=39)	TTE (n=39)	P value
Total procedure time (min)	142.2±71.0 (120±11.3)	149.0±40.0 (142±6.4)	0.032*
Change in creatinine (mg/dL)	-0.13±0.40 (-0.08±0.06)	0.001±.93 (-0.05±0.15)	0.229*
AKI occurrence (VARC-2 criteria) (no. (%))	1 (3)	5 (13)	0.077
Aortograms (no.)	7.7±2.1 (7±0.33)	8.6±1.9 (8.5±0.32)	0.014*
ICU stay (h)	99.5±128 (50±20.5)	70.0±30 (71±5)	0.519*
Length of stay in hospital (days)	6.2±8.1 (4±1.3)	5.4±3.2 (4±0.5)	0.127*

Continuous variables are expressed as mean ± s.d. (median ± s.e.).

\*Comparison was made by Man-Whitney U test as parameters were not normally distributed, AKI occurrence as per VARC-2 criteria.

AKI, acute kidney injury; TEE, transesophageal echocardiography; TTE, transthoracic echocardiography.

**Table 4** Acute procedural TAVR complications (includes post-operative day 0 and post-operative day 1).

Complications	TEE (n=48)	TTE (n=96)	P value
Deaths (no. (%))	2 (4)	0 (0)	0.110
GU bleed (no. (%))	0 (0)	1 (1)	1.000
Access site complications (no. (%))	0 (0)	4 (4)	0.301
Pacemaker (no. (%))	1 (2)	7 (7)	0.269
ICD (no. (%))	0 (0)	1 (1)	1.000
Major vascular complications (no. (%))	1 (2)	1 (1)	1.000
Atrial fibrillation (no. (%))	0 (0)	1 (1)	1.000
Stroke/TIA (no. (%))	4 (8)	0 (0)	0.011

Comparisons were done using the Fisher exact test.

ICD, implantable cardioverter defibrillator; TAVR, transcatheter aortic valve replacement; TEE, transesophageal echocardiography; TTE, transthoracic echocardiography.

the operator to be close to the cardiac apex. Studies have shown that this position is associated with a much higher amount of radiation, particularly to the hand. In one study, the radiation exposure to the hand of a cardiothoracic surgeon undertaking a transapical TAVR was almost 200-fold higher ( $1.9 \pm 0.6 \text{ mSv}$ ) compared to transfemoral TAVR ( $0.03 \pm 0.01 \text{ mSv}$ ) (6). This study also showed that the dose to the feet on the left side of the patient was 3.5 times higher without the extra lead protection on the left side ( $0.14 \pm 0.7 \text{ mSv}$  vs  $0.04 \pm 0.02 \text{ mSv}$ ) and to the eyes was nearly a factor of four higher between transapical and transfemoral procedures ( $0.11 \pm 0.06$  vs  $0.03 \pm 0.01 \text{ mSv}$ ) (6). Although less data exist for the radiation exposure to the imager with TEE positioning at the head of the bed, the increased distance from the Xray tube as well as the ability to use a radiation screen are tools that would significantly decrease the exposure to the echocardiographer.

Our study showed that TEE use during TAVR was associated with a significantly lower procedure time and fluoroscopy time. Several reasons may account for the increased procedure times in the TTE group. For one, supine patient positioning increases the difficulty of attaining the appropriate periprocedural images. In addition, TTE images are obscured by chest wall, tissue or lung hyperinflation in addition to attenuation from calcified mitral or aortic annuluses or interference from prosthetic material. The increased visibility and higher resolution of TEE allows the imager to expertly identify wire and device positioning as well as diagnose complications. In addition to decreasing the radiation exposure to the imager, manipulation of the TEE probe at the head of the bed allows for image acquisition without interruption of fluoroscopy.

There are several limitations associated with our study design. First, this was a retrospective analysis thus potentially associated with a lack of matched data. To account for this, we undertook a propensity-matched

analysis in order to reduce selection bias. Secondly, we did not include the amount of contrast used in each subgroup as this was not accurately recorded, and this will be important to ascertain in future studies. Furthermore, several TAVR groups have adapted to simply using post-procedural TTE for TAVR guidance; however, this is associated with missed opportunities in identifying complications in real time, for instance that of annular rupture. Additionally, we have recently reported a case where use of echocardiography for procedural guidance not only detected annular rupture, but also was able to guide device closure of rupture without need for surgery (34). Additionally, it would be important to record the number of balloon dilatations, which can aid in estimating the amount of contrast as well as fluoroscopy time used. Although our study found an association between the lower number of aortograms and AKI, as well as lower procedure and fluoroscopy times with TEE, future randomized controlled trials will be needed to assess the role of periprocedural TEE in guidance during TAVR procedures.

In conclusion, in addition to providing higher resolution and uninterrupted procedural guidance, the use of TEE with MAC during TAVR is associated with a lower fluoroscopic time, a lower need for additional aortograms and trend in lower post-TAVR AKI. These findings can be utilized when assessing the optimal periprocedural imaging strategy in patients undergoing TAVR.

#### Declaration of interest

Dr Partho P Sengupta is a consultant for Heartsciences and Hitachi Aloka. All other authors have nothing to disclose.

#### Funding

This work did not receive any specific grant from any funding agency in the public, commercial, or not-for-profit sector.



### Acknowledgments

The authors would like to acknowledge Dr. Sunil K Agarwal for his assistance in data analysis and statistics.

### References

- 1 Leon MB, Smith CR, Mack M, Miller DC, Moses JW, Svensson LG, Tuzcu EM, Webb JG, Fontana GP, Makkar RR, *et al.* Transcatheter aortic-valve implantation for aortic stenosis in patients who cannot undergo surgery. *New England Journal of Medicine* 2010 **363** 1597–1607. (<https://doi.org/10.1056/NEJMoa1008232>)
- 2 Smith CR, Leon MB, Mack MJ, Miller DC, Moses JW, Svensson LG, Tuzcu EM, Webb JG, Fontana GP, Makkar RR, *et al.* Transcatheter versus surgical aortic-valve replacement in high-risk patients. *New England Journal of Medicine* 2011 **364** 2187–2198. (<https://doi.org/10.1056/NEJMoa1103510>)
- 3 Popma JJ, Adams DH, Reardon MJ, Yakubov SJ, Kleiman NS, Heimansohn D, Hermiller J Jr, Hughes GC, Harrison JK, Coselli J, *et al.* Transcatheter aortic valve replacement using a self-expanding bioprosthesis in patients with severe aortic stenosis at extreme risk for surgery. *Journal of the American College of Cardiology* 2014 **63** 1972–1981. (<https://doi.org/10.1016/j.jacc.2014.02.556>)
- 4 Adams DH, Popma JJ, Reardon MJ, Yakubov SJ, Coselli JS, Deeb GM, Gleason TG, Buchbinder M, Hermiller J Jr, Kleiman NS, *et al.* Transcatheter aortic-valve replacement with a self-expanding prosthesis. *New England Journal of Medicine* 2014 **370** 1790–1798. (<https://doi.org/10.1056/NEJMoa1400590>)
- 5 Holmes DR Jr, Mack MJ, Kaul S, Agnihotri A, Alexander KP, Bailey SR, Calhoun JH, Carabello BA, Desai MY, Edwards FH, *et al.* 2012 ACCF/AATS/SCAI/STS expert consensus document on transcatheter aortic valve replacement. *Journal of the American College of Cardiology* 2012 **59** 1200–1254. (<https://doi.org/10.1016/j.jacc.2012.01.001>)
- 6 Sauren LD, van Garsee L, van Ommen V & Kemerink GJ. Occupational radiation dose during transcatheter aortic valve implantation. *Catheterization and Cardiovascular Interventions* 2011 **78** 770–776. (<https://doi.org/10.1002/ccd.23116>)
- 7 Anastasian ZH, Strozyk D, Meyers PM, Wang S & Berman MF. Radiation exposure of the anesthesiologist in the neurointerventional suite. *Anesthesiology* 2011 **114** 512–520. (<https://doi.org/10.1097/ALN.0b013e31820c2b81>)
- 8 Pani S, Cagino J, Feustel P, Musuku SR, Raja A, Bruno N, Ursillo C, Arunakul N, Poulos CM, Welljams-Dorof M, *et al.* Patient selection and outcomes of transfemoral transcatheter aortic valve replacement performed with monitored anesthesia care versus general anesthesia. *Journal of Cardiothoracic and Vascular Anesthesia* 2017 **31** 2049–2054. (<https://doi.org/10.1053/j.jvca.2017.04.005>)
- 9 Villablanca PA, Mohananey D, Nikolic K, Bangalore S, Slovut DP, Mathew V, Thourani VH, Rode's-Cabau J, Núñez-Gil IJ, Shah T, *et al.* Comparison of local versus general anesthesia in patients undergoing transcatheter aortic valve replacement: a meta-analysis. *Catheterization and Cardiovascular Interventions* 2018 **91** 330–342. (<https://doi.org/10.1002/ccd.27207>)
- 10 Frohlich GM, Lansky AJ, Webb J, Roffi M, Toggweiler S, Reinthaler M, Wang D, Hutchinson N, Wendler O, Hildick-Smith D, *et al.* Local versus general anesthesia for transcatheter aortic valve implantation (TAVR) – systematic review and meta-analysis. *BMC Medicine* 2014 **12** 41. (<https://doi.org/10.1186/1741-7015-12-41>)
- 11 Cribier A, Eltchaninoff H, Bash A, Borenstein N, Tron C, Bauer F, Derumeaux G, Anselme F, Laborde F & Leon MB. Percutaneous transcatheter implantation of an aortic valve prosthesis for calcific aortic stenosis: first human case description. *Circulation* 2002 **106** 3006–3008. (<https://doi.org/10.1161/01.CIR.0000047200.36165.B8>)
- 12 Hahn RT, Abraham T, Adams MS, Bruce CJ, Glas KE, Lang RM, Reeves ST, Shanewise JS, Siu SC, Stewart W, *et al.* Guidelines for performing a comprehensive transesophageal echocardiographic examination: recommendations from the American Society of Echocardiography and the Society of Cardiovascular Anesthesiologists. *Journal of the American Society of Echocardiography* 2013 **26** 921–964. (<https://doi.org/10.1016/j.echo.2013.07.009>)
- 13 Mayr NP, Michel J, Bleiziffer S, Tassani P & Martin K. Sedation or general anesthesia for transcatheter aortic valve implantation (TAVI). *Journal of Thoracic Disease* 2015 **7** 1518–1526. (<https://doi.org/10.3978/j.issn.2072-1439.2015.08.21>)
- 14 Yamamoto M, Meguro K, Mouillet G, Bergeond E, Monin JL, Lim P, Dubois-Rande JL & Teiger E. Effect of local anesthetic management with conscious sedation in patients undergoing transcatheter aortic valve implantation. *American Journal of Cardiology* 2013 **111** 94–99. (<https://doi.org/10.1016/j.amjcard.2012.08.053>)
- 15 Babaliaros V, Devireddy C, Lerakis S, Leonardi R, Iturra SA, Mavromatis K, Leshnower BG, Guyton RA, Kanitkar M, Keegan P, *et al.* Comparison of transfemoral transcatheter aortic valve replacement performed in the catheterization laboratory (minimalist approach) versus hybrid operating room (standard approach): outcomes and cost analysis. *JACC: Cardiovascular Interventions* 2014 **7** 898–904. (<https://doi.org/10.1016/j.jcin.2014.04.005>)
- 16 Nishimura RA, Otto CM, Bonow RO, Carabello BA, Erwin JP 3rd, Guyton RA, O'Gara PT, Ruiz CE, Skubas NJ, Sorajja P, *et al.* 2014 AHA/ACC guideline for the management of patients with valvular heart disease: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines. *Journal of Thoracic and Cardiovascular Surgery* 2014 **148** e1–e132. (<https://doi.org/10.1016/j.jtcvs.2014.05.014>)
- 17 Pibarot P, Hahn RT, Weissman NJ & Monaghan MJ. Assessment of paravalvular regurgitation following TAVR: a proposal of unifying grading scheme. *JACC Cardiovascular Imaging* 2015 **8** 340–360. (<https://doi.org/10.1016/j.jcmg.2015.01.008>)
- 18 Zoghbi WA, Enriquez-Sarano M, Foster E, Grayburn PA, Kraft CD, Levine RA, Nihoyannopoulos P, Otto CM, Quinones MA, Rakowski H, *et al.* Recommendations for evaluation of the severity of native valvular regurgitation with two-dimensional and Doppler echocardiography. *Journal of the American Society of Echocardiography* 2003 **16** 777–802. ([https://doi.org/10.1016/S0894-7317\(03\)00335-3](https://doi.org/10.1016/S0894-7317(03)00335-3))
- 19 Genereux P, Head SJ, Van Mieghem NM, Kodali S, Kirtane AJ, Xu K, Smith C, Serruys PW, Kappetein AP & Leon MB. Clinical outcomes after transcatheter aortic valve replacement using valve academic research consortium definitions: a weighted meta-analysis of 3,519 patients from 16 studies. *Journal of the American College of Cardiology* 2012 **59** 2317–2326. (<https://doi.org/10.1016/j.jacc.2012.02.022>)
- 20 Kappetein AP, Head SJ, Genereux P, Piazza N, van Mieghem NM, Blackstone EH, Brott TG, Cohen DJ, Cutlip DE, van Es GA, *et al.* Updated standardized endpoint definitions for transcatheter aortic valve implantation: the Valve Academic Research Consortium-2 consensus document. *European Heart Journal* 2012 **33** 2403–2418. (<https://doi.org/10.1093/eurheartj/ehs255>)
- 21 Agarwal S, Tuzcu EM, Stewart W, Bajaj NS, Svensson LG & Kapadia SR. Comparison of multicenter registries and randomized control trials for transcatheter aortic valve replacement (TAVR). *Indian Heart Journal* 2013 **65** 400–411. (<https://doi.org/10.1016/j.ihj.2013.06.007>)
- 22 de Brito FS Jr, Carvalho LA, Sarmiento-Leite R, Mangione JA, Lemos P, Siciliano A, Caramori P, São Thiago L, Grube E, Abizaid A, *et al.* Outcomes and predictors of mortality after transcatheter aortic valve implantation: results of the Brazilian registry. *Catheterization and Cardiovascular Interventions* 2015 **85** E153–E162. (<https://doi.org/10.1002/ccd.25778>)
- 23 Chiang CW, Huang HL & Ko YS. Echocardiography-guided balloon mitral valvotomy: transesophageal echocardiography versus



- intracardiac echocardiography. *Journal of Heart Valve Disease* 2007 **16** 596–601.
- 24 Vilacosta I, Iturralde E, San Roman JA, Gomez-Recio M, Romero C, Jimenez J & Martínez-Elbal L. Transesophageal echocardiographic monitoring of percutaneous mitral balloon valvulotomy. *American Journal of Cardiology* 1992 **70** 1040–1044. ([https://doi.org/10.1016/0002-9149\(92\)90357-5](https://doi.org/10.1016/0002-9149(92)90357-5))
- 25 Applebaum RM, Kasliwal RR, Kanojia A, Seth A, Bhandari S, Trehan N, Winer HE, Tunick PA & Kronzon I. Utility of three-dimensional echocardiography during balloon mitral valvuloplasty. *Journal of the American College of Cardiology* 1998 **32** 1405–1409. ([https://doi.org/10.1016/S0735-1097\(98\)00386-6](https://doi.org/10.1016/S0735-1097(98)00386-6))
- 26 Kultursay H, Turkoglu C, Akin M, Payzin S, Soydas C & Akilli A. Mitral balloon valvuloplasty with transesophageal echocardiography without using fluoroscopy. *Catheterization and Cardiovascular Diagnosis* 1992 **27** 317–321. (<https://doi.org/10.1002/ccd.1810270414>)
- 27 Silvestry FE, Kerber RE, Brook MM, Carroll JD, Eberman KM, Goldstein SA, Herrmann HC, Homma S, Mehran R, Packer DL, *et al.* Echocardiography-guided interventions. *Journal of the American Society of Echocardiography* 2009 **22** 213–231. (<https://doi.org/10.1016/j.echo.2008.12.013>)
- 28 Cheungpasitporn W, Thongprayoon C & Kashani K. Transcatheter aortic valve replacement: a kidney's perspective. *Journal of Renal Injury Prevention* 2016 **5** 1–7. (<https://doi.org/10.15171/jrip.2016.01>)
- 29 Genereux P, Kodali SK, Green P, Paradis JM, Daneault B, Rene G, Hueter I, Georges I, Kirtane A, Hahn RT, *et al.* Incidence and effect of acute kidney injury after transcatheter aortic valve replacement using the new valve academic research consortium criteria. *American Journal of Cardiology* 2013 **111** 100–105. (<https://doi.org/10.1016/j.amjcard.2012.08.057>)
- 30 Bagur R, Webb JG, Nietlispach F, Dumont E, De Laroche L, Doyle D, Masson JB, Gutiérrez MJ, Clavel MA, Bertrand OF, *et al.* Acute kidney injury following transcatheter aortic valve implantation: predictive factors, prognostic value, and comparison with surgical aortic valve replacement. *European Heart Journal* 2010 **31** 865–874. (<https://doi.org/10.1093/eurheartj/ehp552>)
- 31 Thongprayoon C, Cheungpasitporn W, Srivali N, Harrison AM, Gunderson TM, Kittanamongkolchai W, Greason KL & Kashani KB. AKI after transcatheter or surgical aortic valve replacement. *Journal of the American Society of Nephrology* 2016 **27** 1854–1860. (<https://doi.org/10.1681/ASN.2015050577>)
- 32 Ferrari E, Sulzer C, Marcucci C, Rizzo E, Tozzi P & von Segesser LK. Transapical aortic valve implantation without angiography: proof of concept. *Annals of Thoracic Surgery* 2010 **89** 1925–1932. (<https://doi.org/10.1016/j.athoracsur.2010.02.047>)
- 33 Bagur R, Rodes-Cabau J, Doyle D, De Laroche L, Villeneuve J, Lemieux J, Bergeron S, Côté M, Bertrand OF, Pibarot P, *et al.* Usefulness of TEE as the primary imaging technique to guide transcatheter transapical aortic valve implantation. *JACC Cardiovascular Imaging* 2011 **4** 115–124. (<https://doi.org/10.1016/j.jcmg.2010.10.009>)
- 34 Alkhouli M, Carpenter E, Tarabishy A & Sengupta P. Annular rupture during transcatheter aortic valve replacement: novel treatment with amplatzer vascular plugs. *European Heart Journal* 2018 **39** 714–715. (<https://doi.org/10.1093/eurheartj/ehx654>)

Received in final form 6 May 2018

Accepted 9 May 2018

Accepted Preprint published online 9 May 2018