ECRONICON OPEN ACCESS

EC CARDIOLOGY
Research Article

Computed Tomography Versus Transesophageal Echocardiography for Sizing of Transcatheter Aortic Valve Replacement: A Meta-Analysis to Assess Differences in Post-Procedure Complications

Rohit Seth Loomba[1]*, Saurabh Aggarwal[2], Navdeep Gupta[1], Anushree Agarwal[3], Parinda Shah[4], Gaurav Aggarwal[5], Manu Kaushik[2], Venkata Mahesh Alla[2], Rohit Romesh Arora[6], Aryan Mooss[2] and Bijoy Khandheria[7]

[1]Medical College of Wisconsin, Milwaukee, WI, USA

[2]Creighton University School of Medicine, Omaha, NE, USA

[3]University of California, San Francisco, CA, USA

[4]Advocate Illinois Masonic Medical Center, Chicago, IL, USA

[5]Armed Forces Medical College, Pune, India

[6]Department of Medicine, Chicago Medical School, North Chicago, IL, USA

[7]Aurora Sinai/Aurora St. Luke's Medical Center, Milwaukee, WI, USA

***Corresponding Author**: Rohit Seth Loomba, Medical College of Wisconsin, Milwaukee, WI, USA.

Received: April 04, 2017; **Published:** April 26, 2017

Abstract

Appropriate sizing of the TAVR annular ring is crucial to prevent paravalvular aortic regurgitation (PAR). Multiple studies have been done comparing the use of conventional 2-D transesophageal echocardiography (TEE) versus multidetector computed tomography (MDCT) for appropriate sizing, on the PAR outcomes after TAVR. We aimed to perform a meta-analysis of the published studies. Pubmed, Embase and Cochrane databases were searched using the search terms multidetector computed tomography, transesophageal echocardiography, transcatheter aortic valve replacement, paravalvular aortic regurgitation and various combinations. The fixed effects model was used for analysis of homogenous endpoints, and the random effects model for heterogeneous endpoints. Forest plots were drawn. $P < 0.05$ was considered significant. Compared to TEE-based annular ring sizing, MDCT was associated with a significant decrease in greater than mild PAR (odds ratio (OR) 0.42; 95% confidence interval (CI) 0.28 to 0.63; $p < 0.0001$) and severe PAR (OR 0.41; 95% CI 0.17 to 0.96; $p = 0.04$). No significant differences were found in rates of annular rupture (OR 0.96; 95% CI 0.25 to 3.72; $p = 0.95$), no PAR (OR 1.43; 95% CI 0.98 to 2.08; $p = 0.06$), mild PAR (OR 1.21; 95% CI 0.85 to 1.73; $p = 0.28$), need for pacemaker implantation (OR 1.00; 95% CI 0.58 to 1.73; $p = 0.99$) and procedural mortality (OR 0.99; 95% CI 0.23 to 4.26; $p = 0.99$). Heterogeneity analysis showed none of the endpoints had significant heterogeneity. MDCT-based annular ring sizing was associated with significant decreases in greater than mild and severe paravalvular aortic regurgitation after TAVR, when compared to 2D TEE.

Keywords: *Computed Tomography; Transesophageal Echocardiography; Transcatheter Aortic Valve Replacement*

Introduction

Although not a new concept, transcatheter aortic valve replacement (TAVR) has recently become increasingly more popular secondary to technical advancements with catheter based interventions as well as improvements in the technology itself. Catheter based aortic valves were described as early as the 1960s for relief of aortic insufficiency [1-4]. It was in the early 1990s that Cribier., *et al*. demonstrated a series of successful stent deployments in heavily calcified aortic valves that eventually resulted in a clinical case being performed in 2002 using a 23 mm stent mounted aortic valve [5]. Since then, TAVR has been demonstrated to impart a survival benefit in those who are not candidates for surgical aortic valve replacement and to impose no increased risk to those who are high risk surgical candidates [6,7].

Valves used for TAVR are now available in various sizes and appropriate size selection is of utmost importance as it can influence morbidity and mortality. Undersized valves are associated with paravalvular regurgitation and device embolization while oversized valves are associated with annular rupture, coronary occlusion, and heart block requiring pacemaker placement [8-12]. Sizing of valves was initially described using transesophageal echocardiography (TEE) although this may not be ideal as this is a two-dimensional modality being utilized to image a three-dimensional structure with complex, dynamic geometry [13]. Three-dimensional imaging modalities offering improved ability to visualize the irregular geometry and contours of the aortic valve, such as computed tomography (CT) are now being studied for sizing of valves in TAVR [14,15].

Recent studies have compared outcomes after TAVR after sizing by TEE only and those with CT data available. This study offers a meta-analysis of available data with the aim of further characterizing the utility of CT in sizing of TAVR valves.

Methods

Endpoints

A systematic review of the literature was performed to identify manuscripts describing comparisons between CT and TEE in sizing appropriate valves for TAVR. This was a newly conducted review with no previous review protocol having been established for it. The aim of the study was to identify whether CT or TEE allows for better sizing of valves in TAVR using the following postinterventional outcomes: annular rupture, valvar regurgitation, need for pacemaker, and procedural mortality.

Manuscript Search and Identification Strategy

Manuscripts were identified using electronic databases including PubMed, EMBASE, and Ovid which were queried using the following search terms: “transcatheter aortic valve replacement”, “TAVR”, “transcatheter aortic valve implantation” or “TAVI” in conjunction with one of the following: “computerized tomography”, “CT”, “transesophageal echocardiography”, or “TEE”. No specific restriction on year of publication was used. Resulting studies were then screened by title and abstract with manuscripts describing TAVR and either CT or TEE being retrieved in their entirety. References of these were hand searched for additional relevant manuscripts. No direct with manuscript authors was required to obtain full text manuscripts.

These full text manuscripts were then reviewed by two of the authors and assessed for quality (SA and KN). Any disparities in scoring of manuscripts were then independently reviewed by another author (RA). The Cochrane Handbook for Systematic Review of Interventions was used or quality evaluation. Published manuscripts available in full text were included in this review if they presented data from prospective or randomized trials comparing TAVR sizing by CT and TEE with respect to the outcomes listed above. Studies were included in this analysis if they included at least one of the outcomes identified above.

Data Extraction

Next, data regarding baseline patient characteristics and identified outcomes were extracted from the manuscripts identified for inclusion. Trial level data was independently with use of a data collection form by two authors (SA and RL). The data extraction was then independently reviewed by another author (PS) to ensure integrity of the resulting data. If no information was available about particular outcomes this was designated separately. Authors of included studies were not contacted for additional data.

Bias Analysis

Bias was assessed using the physiotherapy evidence database (PEDro) scale. Specifically, patient eligibility, randomization and concealment of allocation, blinding, completeness of outcome data, and statistical integrity were assessed using this scale. Blinding in these studies referred specifically to TEE operators not being aware of CT sizing recommendations.

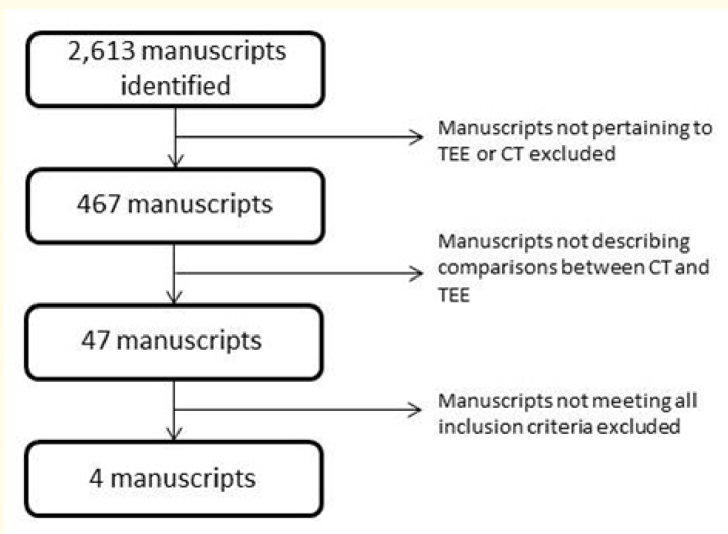
Data Analysis

Numeric data is presented as means with standard deviations or medians with ranges. Categorical data is presented as frequencies with absolute numbers as well as percentages. P-values of ≤ 0.05 were considered statistically significant. This analysis was done using SPSS statistical software, version 20.0 (Chicago, IL). Meta-analysis and forest plot creation were done using RevMan 5.0 (Cochrane Collaboration, Oxford, UK). Results are presented as pooled odds ratios with 95% confidence intervals or as standard mean difference where appropriate. Heterogeneity between studies was identified using chi-square and I^2tests. For outcomes with no significant heterogeneity present a fixed effects model was used. Otherwise a random effects model was used if either the p-value was significant or the I^2 statistics was greater than 50%.

Results

Study Identification

Using simply "transcatheter aortic valve implantation" or "transcatheter aortic valve replacement" as the search term, 2,613 unique manuscripts were identified. When this was combined with the term "computed tomography" or "transesophageal echocardiography" then 467 unique manuscripts were identified. Once titles and abstracts were reviewed to identify studies comparing TEE and CT, 47 manuscripts were identified. Full-text of all these manuscripts was successfully obtained and reviewed. Ultimately, 4 of these manuscripts met inclusion criteria for the pooled analysis [9,16-18] (Figure 1).



Baseline Characteristics

Of the 4 studies that were identified for inclusion in the analysis, 3 were retrospective and 1 prospective. Total number of patients in the studies ranged from 136 to 350 with a total of 890 in the pooled analysis, 484 in the TEE only group and 406 in the CT group. Average age ranged from 81 to 84 years with no significant difference between the TEE and CT groups within each study or amongst all studies. In 3 of the studies the TEE and CT groups consisted of 45 to 52% males although in one study the groups consisted of 76% and 84% males, respectively. Aortic valve area, mean aortic pressure gradient, percentage of patients with New York Heart Association (NYHA) class III/IV heart failure, and glomerular filtration rate also did not vary within each study or amongst all studies. The logistic euroSCORE, however, did demonstrate significant difference with the TEE only and CT groups presented by Hayashida., *et al*. with those in the TEE only group having statistically significant higher scores (Table 1).

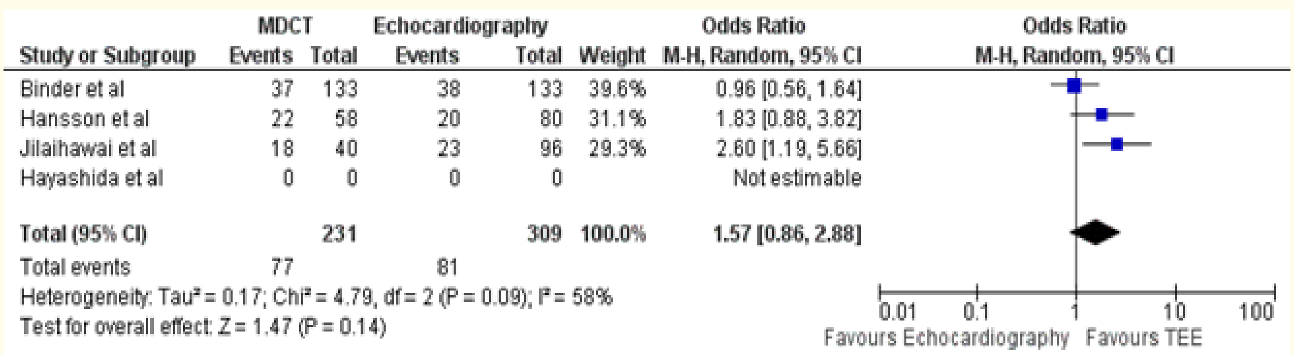
Study	Hayashida	Binder	Hansson	Jilaihawi
Year	2012	2013	2013	2012
Study Design	Retrospective	Prospective	Retrospective	Retrospective
N (total) TEE only CT	350 175 175	266 133 133	138 80 58	136 96 40
Age TEE only CT	83.3 ± 6.4 83.2 ± 6.4	81.0 ± 8.0 82.0 ± 8.0	81.2 ± 6.9 82.6 ± 6.0	84.9 ± 7.2 82.4 ± 10.2
Male gender TEE only CT	87 (49.7%) 91 (52.0%)	57 (76.0%) 63 (84.0%)	41 (51.2%) 26 (44.8%)	50 (52.1%) 18 (45.0%)
Aortic valve area (cm/m^2) TEE only CT	0.62 ± 0.16 0.64 ± 0.13	0.70 ± 0.20 0.70 ± 0.20	0.67 ± 0.20 0.67 ± 0.19	-- --
Mean pressure gradient (mmHg) TEE only CT	47.0 ± 16.5 48.3 ± 16.5	38.0 ± 15.0 42.0 ± 18.0	-- --	45.3 ± 4.5 45.6 ± 2.8
Logistic euroSCORE TEE only CT	24.4 ± 11.5* 20.1 ± 10.4*	-- --	23.2 ± 16.1 18.9 ± 12.6	31.2 ± 16.1 27.5 ± 14.5
NYHA class III/IV TEE only CT	147 (84.0%) 150 (82.6%)	112 (84.0%) 96 (84.9%)	70 (87.5%) 45 (77.6%)	-- --
GFR (ml/min) TEE only CT	-- --	53.0 ± 20.0 62.0 ± 24.0	51.2 ± 21.1 58.1 ± 19.2	-- --
Bicuspid aortic valve TEE only CT	1 (0.6%)* 15 (8.6%)*	-- --	-- --	-- --
Early TAVI experience excluded?	Yes	--	Yes	--
Valves used	Edwards SAPIEN, CoreValve	Edwards SAPIEN	Edwards SAPIEN	Edwards SAPIEN
29 mm valves used?	Yes	Yes	Yes	No
Patients excluded from study due to renal contraindications to CT scan?	No	Yes	Yes	Yes
Malposed valves excluded from analysis	No	No	Yes	Yes

**significant difference between values within study (p < 0.01)*

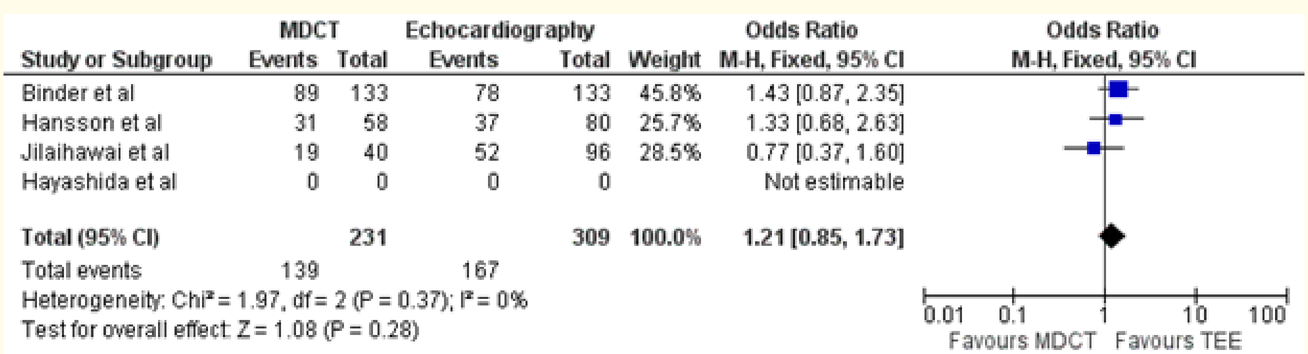
Of the studies included, 3 exclusively used the Edwards SAPIEN valve while the study by Hayashida., *et al*. did also use the Medtronic CoreValve. All studies used a 29 mm valve where deemed necessary except for the study by Jilaihawi., *et al*. due to the unavailability of the 29 mm valve in the United States. All studies except for Hayashida *et al*. excluded patients from the study if there were renal contraindications to a CT scan. Two studies also excluded patients from analysis if valves were deemed malposed by postinterventional echocardiography (Table 1).

Perivalvular Regurgitation

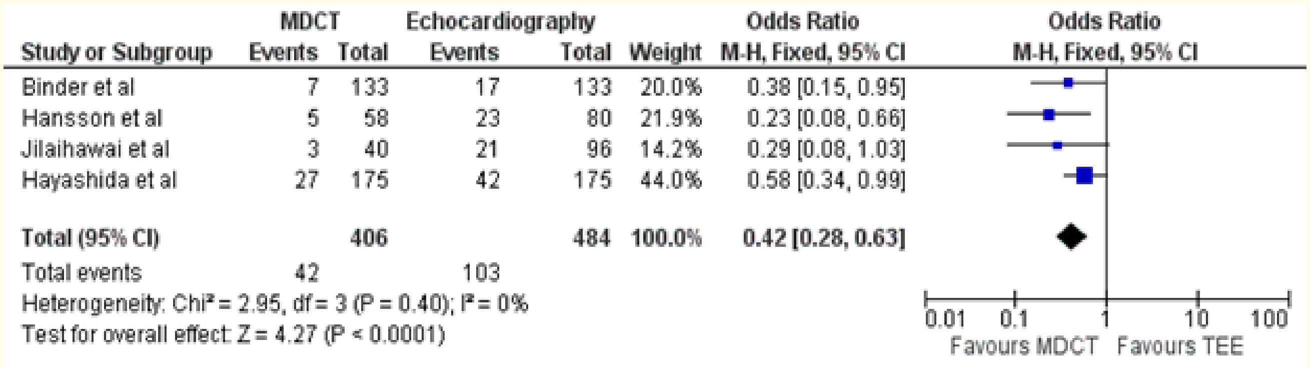
There was no statistically significant difference in the absence of paravalvular regurgitation between those in the CT versus TEE only groups (odds ratio 1.57, 95% confidence interval 0.86 to 2.88). A random effects model was used as chi-squared analysis of heterogeneity resulted in a p-value of 0.09 with an I2 of 58% (Figure 2).



There was no statistically significant difference in mild paravalvular regurgitation between those in the CT versus TEE only groups (odds ratio 1.21, 94% confidence interval 0.385 to 1.73). A fixed effects model was used as chi-squared analysis of heterogeneity resulted in a p-value of 0.37 with an I2 of 0% (Figure 3).



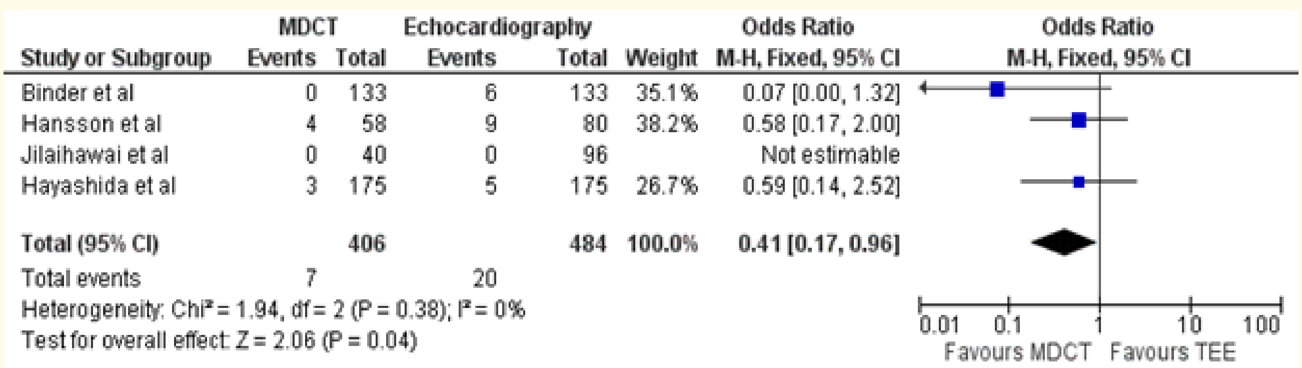
The occurrence of more than mild paravalvular regurgitation was significantly lower in the CT group when compared to the TEE only group (odds ratio 0.42, 95% confidence interval 0.28 to 0.63). A fixed effects model was used as chi-squared analysis resulted in a p-value of 0.40 with an I2 of 0% (Figure 4).



Study or Subgroup	MDCT Events	MDCT Total	Echocardiography Events	Echocardiography Total	Weight	Odds Ratio M-H, Fixed, 95% CI
Binder et al	7	133	17	133	20.0%	0.38 [0.15, 0.95]
Hansson et al	5	58	23	80	21.9%	0.23 [0.08, 0.66]
Jilaihawai et al	3	40	21	96	14.2%	0.29 [0.08, 1.03]
Hayashida et al	27	175	42	175	44.0%	0.58 [0.34, 0.99]
Total (95% CI)		**406**		**484**	**100.0%**	**0.42 [0.28, 0.63]**
Total events	42		103			

Heterogeneity: Chi² = 2.95, df = 3 (P = 0.40); I² = 0%
Test for overall effect: Z = 4.27 (P < 0.0001)

The occurrence of severe paravalvular regurgitation was significantly lower in the CT group when compared to the TEE only group (odds ratio 0.41, 95% confidence interval 0.17 to 0.96). A fixed effect model was used as chi-square analysis of heterogeneity resulted in a p-value of 0.38 with an I2 of 0% (Figure 5).

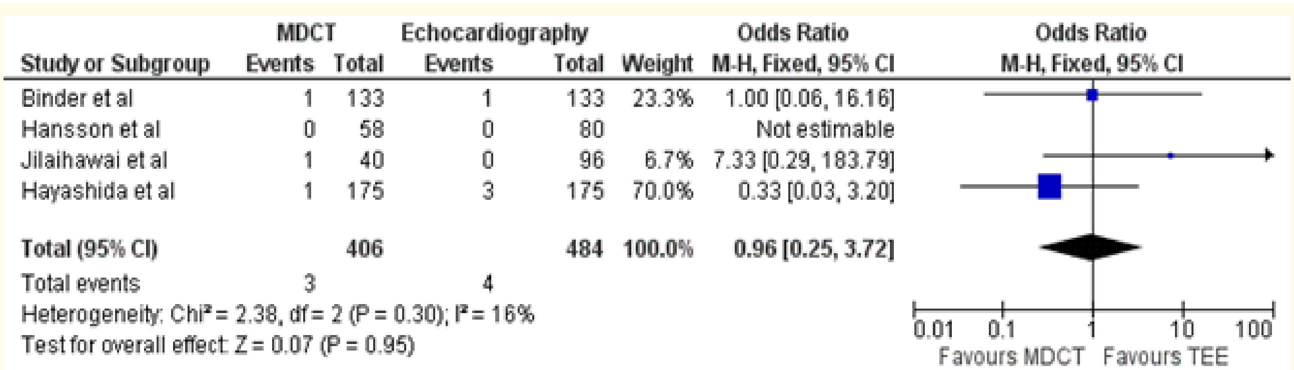


Study or Subgroup	MDCT Events	MDCT Total	Echocardiography Events	Echocardiography Total	Weight	Odds Ratio M-H, Fixed, 95% CI
Binder et al	0	133	6	133	35.1%	0.07 [0.00, 1.32]
Hansson et al	4	58	9	80	38.2%	0.58 [0.17, 2.00]
Jilaihawai et al	0	40	0	96		Not estimable
Hayashida et al	3	175	5	175	26.7%	0.59 [0.14, 2.52]
Total (95% CI)		**406**		**484**	**100.0%**	**0.41 [0.17, 0.96]**
Total events	7		20			

Heterogeneity: Chi² = 1.94, df = 2 (P = 0.38); I² = 0%
Test for overall effect: Z = 2.06 (P = 0.04)

Annular Rupture

There was no statistically significant difference in annular rupture between the CT and TEE only group (odds ratio 0.96, 95% confidence interval 0.25 to 3.72). A fixed effect model was used as chi-square analysis resulted in a p-value of 0.30 with an I2 of 16% (Figure 6).

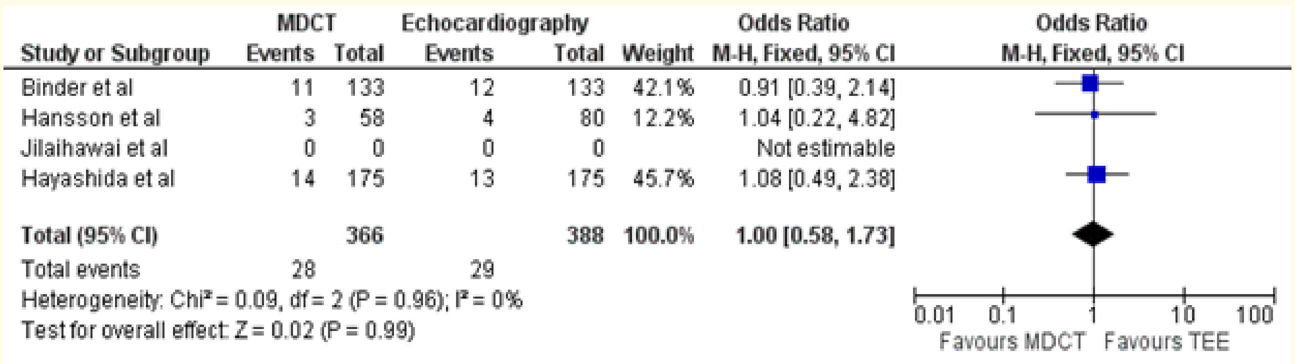


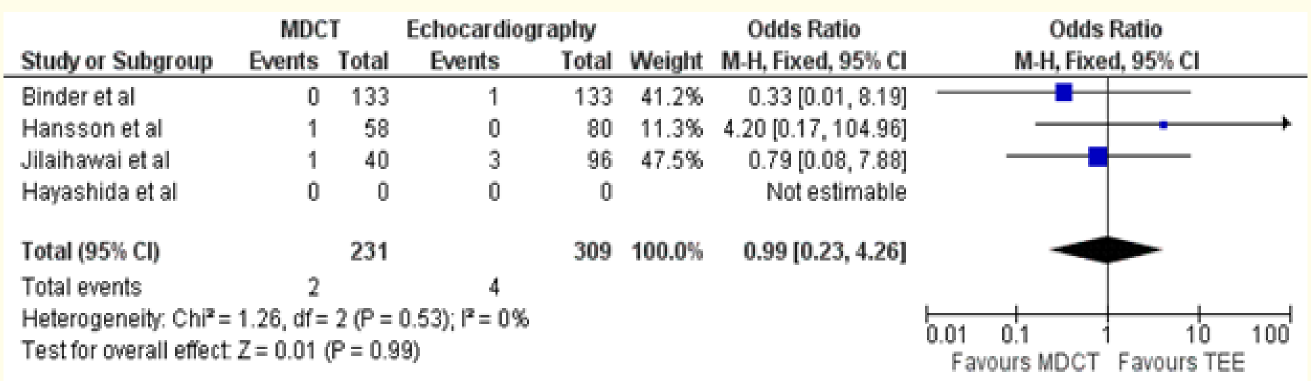
Study or Subgroup	MDCT Events	MDCT Total	Echocardiography Events	Echocardiography Total	Weight	Odds Ratio M-H, Fixed, 95% CI
Binder et al	1	133	1	133	23.3%	1.00 [0.06, 16.16]
Hansson et al	0	58	0	80		Not estimable
Jilaihawai et al	1	40	0	96	6.7%	7.33 [0.29, 183.79]
Hayashida et al	1	175	3	175	70.0%	0.33 [0.03, 3.20]
Total (95% CI)		**406**		**484**	**100.0%**	**0.96 [0.25, 3.72]**
Total events	3		4			

Heterogeneity: Chi² = 2.38, df = 2 (P = 0.30); I² = 16%
Test for overall effect: Z = 0.07 (P = 0.95)

Need for Pacemaker

There was no statistically significant difference in need for pacemaker between the CT and TEE only group (odds ratio 1.00, 95% confidence interval 0.58 to 1.73). A fixed effect model was used as chi-square analysis resulted in a p-value of 0.96 with an I2 of 0% (Figure 7,8).





Procedural Mortality

There was no statistically significant difference in procedural mortality between the CT and TEE only group (odds ratio 0.99, 95% confidence interval 0.23 to 4.26). A fixed effect model was used as chi-square analysis resulted in a p-value of 0.53 with an I2 of 0%.

Bias

Subjective analysis of bias, with respect to patient selection, patient allocation, blinding, and outcome reporting, resulted in minimal overall bias amongst the included studies. Forest plot analysis of publication bias was not conducted due to the low number of available studies and the relative similarity in size of all included studies.

Study	Random Sequence Generation	Allocation Concealment	Blinding	Incomplete Outcome Data
Hayashida., *et al.*	Unclear	Low	Low	Unclear
Binder., *et al.*	Unclear	Low	Low	Low
Hansson., *et al.*	Unclear	Low	Low	Unclear
Jilaihawi., *et al.*	Unclear	Low	Low	Low

Bias analysis for included studies

Study	Selection	Comparability	Outcome	Overall
Hayashida., *et al.*	3	2	3	8
Binder., *et al.*	4	2	3	9
Hansson., *et al.*	3	2	3	8
Jilaihawi., *et al.*	4	2	3	9

Quality assessment of included studies using the Newcastle-Ottawa Assessment Scale.

Discussion

Since its introduction in humans, TAVR has become increasingly popular. With demonstrated benefit in those who have contraindications to surgical aortic valve replacement and with no demonstrated harm in those that are high risk surgical candidates, TAVR has become more frequent [6,7]. Newer trials are now even studying the role of TAVR to lower risk surgical candidates [19,20]. As operator ability and valve technology improve it is likely that the role of TAVR continues to expand and thus it is important to identify areas where progress remains to be made. One such area is that of selecting the appropriate size valve.

While TEE has been described and used for sizing, it is limited by its two-dimensional imaging of a three-dimensional valve. Because of this many have suspected that CT may offer improved ability to select an appropriate size valve. Studies using surgical sizing as a reference have demonstrated improved valve sizing with CT when compared to TEE [21,22]. We identified 4 studies that compared outcomes after TAVR in those who underwent sizing via TEE only or with CT and performed a meta-analysis [9,16-18]. Greater than mild paravalvular regurgitation was nearly 60% less frequent in those who underwent CT. A similar decrease was found in severe regurgitation amongst those who underwent CT scan. There were no differences noted with respect to annular rupture, need for pacemaker, or procedural mortality in the TEE only versus CT group. The pooled findings were similar to those of the individual studies.

Paravalvular regurgitation is an important consequence of TAVR as it is an independent risk factor for short-term and long-term mortality [23,24]. Paravalvular regurgitation is more frequent after TAVR with nearly 12.2% of patients having moderate or severe paravalvular regurgitation compared to 0.9% after surgical aortic valve replacement [7]. This regurgitation is secondary to an incomplete seal of the native annulus by the valve, partly due to tissue which remains from the native aortic valve which is simply against the sides of aorta. Current sizing algorithms try to minimize the risk of moderate to severe paravalvular regurgitation by oversizing the TAVR valve by at least 1mm of the annular diameter or 10% of the annular area, with many oversizing valves by 2 to 5mm in comparison to the annular diameter and up to 20% in comparison to the annular area [8].

Two of the included studies set forth to identify factors that are predictive of paravalvular regurgitation. Jilaihawi., *et al.* studied several echocardiographic and TEE parameters to identify predictors of paravalvular regurgitation and found that the difference between the maximum annular diameter and TAVR size was most predictive feature after multivariate analysis. The only other predictor identified after multivariate analysis was any calcification of the left ventricular outflow tract, both measures only attainable by CT [9]. Hayashida., *et al*. identified the same predictive parameter [16]. This is in contrast to a previous study by Willson., *et al*. that identified annular area as being the most predictive of paravalvular regurgitation [8].

Annular area and maximum annular diameter can both be assessed by CT and thus the question of which to use for sizing arises. While two of the studies, as discussed above, identified annular diameter as being predictive of paravalvular regurgitation, others have demonstrated annular area as being the most predictive [8]. Secondly, annular area has been shown to be more reproducible than annular diameter, in part due to the dynamic nature of this measure in relation to the cardiac cycle. Because of its reproducibility, the use of the mean annular area to size valves has been suggested at this time [8,14,25]. The Edwards SAPIEN XT is available with diameters of 20 mm, 23 mm, 26 mm, and 29 mm which have areas of 3.14 cm^2, 4.15 cm^2, 5.31 cm^2, and 6.61 cm^2, respectively.

A standard ECG-gated protocol can be used for the CT. Gantry rotation time of 330ms with 120kV tube voltage on 64-slice scanner should yield images adequate for necessary anatomic visualization and allow for measurements to be made. Scans can be done with or without beta blockade depending on the patient's heart rate and an 80ml dose of radiopaque contrast should be adequate for imaging. Measurements of the aortic valve should be made in an oblique plane which demonstrates the aortic valve en face such that all three cusps are visible in the same plane and the valve appears to be oval. This plane should also be perpendicular to the long axis plane of the aorta [26,27]. Measurements should be made in mid-systole which should be approximately at 20% to 30% of the R-R interval. Maximum intensity projection can be applied to a selected 20 mm aortic valve slice in mid-diastole to determine degree of calcification with previously described methodology [28].

It is important to note that randomized controlled trials in which catheterization operators are obligated to size based off of only TEE or CT data may be unwise. CT should be used in conjunction with TEE such that operators can make the decision with all available imaging data alongside the clinical data available to them. Additionally, obligating operators to adhere to sizing strictly based off imaging data may not be ideal. Studies included in this analysis that documented operator deviation from CT suggested valve sizing demonstrate that in these instances none of these patients suffered from moderate or severe paravalvular regurgitation [16].

The strengths of this meta-analysis include limited heterogeneity, uniform study size, and similar reported outcomes amongst most included studies. Bias also remained limited amongst studies, although publication bias was not analyzed due to the number of included studied and the relative similarity in patient number. Limitations of this meta-analysis include the retrospective nature of most of the studies. Additionally, the catheterization operators had discretion over the final valve size in either group. They did not have to adhere to predefined sizing algorithms. Additionally, for those with CT data, the catheterization operators did not have to necessarily use that data to guide valve size but simply had it available to them. Most studies did report if such deviation was present and provided rationale for these instances.

Conclusion

Three-dimensional imaging with CT enhances sizing in TAVR and leads to a reduction in moderate and severe paravalvular regurgitation, an independent risk factor for morbidity and mortality. There does not seem to be reduction in annular rupture or pacemaker placement afforded by CT. Those undergoing TAVR should have both TEE and CT data available for sizing.

Bibliography

1. Davies H. "Catheter-mounted valve for temporary relief of aortic insufficiency". *Lancet* 285.7379 (1965): 250.
2. Moulopoulos SD., *et al*. "Catheter-mounted aortic valves". *The Annals of Thoracic Surgery* 11.5 (1971): 423-430.
3. Phillips SJ., *et al*. "A temporary catheter-tip aortic valve: hemodynamic effects on experimental acute aortic insufficiency". *The Annals of Thoracic Surgery* 21.2 (1976): 134-137.
4. Andersen HR., *et al*. "Transluminal implantation of artificial heart valves. Description of a new expandable aortic valve and initial results with implantation by catheter technique in closed chest pigs". *European Heart Journal* 13.5 (1992): 704-708.
5. Cribier A., *et al*. "Percutaneous transcatheter implantation of an aortic valve prosthesis for calcific aortic stenosis: first human case description". *Circulation* 106.24 (2002): 3006-3008.
6. Leon MB., *et al*. "Transcatheter aortic-valve implantation for aortic stenosis in patients who cannot undergo surgery". *The New England Journal of Medicine* 363.17 (2010): 1597-1607.
7. Smith CR., *et al*. "Transcatheter versus surgical aortic-valve replacement in high-risk patients". *The New England Journal of Medicine* 364.23 (2011): 2187-2198.

8. Willson AB., *et al*. "3-dimensional aortic annular assessment by multidetector computed tomography predicts moderate or severe paravalvular regurgitation after transcatheter aortic valve replacement: a multicenter retrospective analysis". *Journal of the American College of Cardiology* 59.14 (2012): 1287-1294.

9. Jilaihawi H., *et al*. "Cross-sectional computed tomographic assessment improves accuracy of aortic annular sizing for transcatheter aortic valve replacement and reduces the incidence of paravalvular aortic regurgitation". Journal of the American College of Cardiology 59.14 (2012): 1275-1286.

10. Blanke P., *et al*. "Prosthesis oversizing in balloon-expandable transcatheter aortic valve implantation is associated with contained rupture of the aortic root". *Circulation Cardiovascular Interventions* 5.4 (2012): 540-548.

11. Tay EL., *et al*. "Outcome of patients after transcatheter aortic valve embolization". *JACC Cardiovascular Interventions* 4.2 (2011): 228-234.

12. Jilaihawi H., *et al*. "Meta-analysis of complications in aortic valve replacement: comparison of Medtronic-Corevalve, Edwards-Sapien and surgical aortic valve replacement in 8,536 patients". *Catheterization and Cardiovascular Interventions* 80.1 (2012): 128-138.

13. Moss RR., *et al*. "Role of echocardiography in percutaneous aortic valve implantation". *JACC Cardiovascular Imaging* 1.1 (2008): 15-24.

14. Gurvitch R., *et al*. "Aortic annulus diameter determination by multidetector computed tomography: reproducibility, applicability, and implications for transcatheter aortic valve implantation". *JACC Cardiovascular Interventions* 4.11 (2011): 1235-1245.

15. Tops LF., *et al*. "Noninvasive evaluation of the aortic root with multislice computed tomography implications for transcatheter aortic valve replacement". *JACC Cardiovascular Imaging* 1.3 (2008): 321-330.

16. Hayashida K., *et al*. "Impact of CT-guided valve sizing on post-procedural aortic regurgitation in transcatheter aortic valve implantation". *EuroIntervention* 8.5 (2012): 546-555.

17. Binder RK., *et al*. "The impact of integration of a multidetector computed tomography annulus area sizing algorithm on outcomes of transcatheter aortic valve replacement: a prospective, multicenter, controlled trial". *Journal of the American College of Cardiology* 62.5 (2013): 431-438.

18. Hansson NC., *et al*. "Three-dimensional multidetector computed tomography versus conventional 2-dimensional transesophageal echocardiography for annular sizing in transcatheter aortic valve replacement: Influence on postprocedural paravalvular aortic regurgitation". *Catheterization and Cardiovascular Interventions* 82.6 (2013): 977-986.

19. Piazza N., *et al*. "A 3-center comparison of 1-year mortality outcomes between transcatheter aortic valve implantation and surgical aortic valve replacement on the basis of propensity score matching among intermediate-risk surgical patients". *JACC Cardiovascular Interventions* 6.5 (2013): 443-451.

20. Wenaweser P., *et al*. "Clinical outcomes of patients with estimated low or intermediate surgical risk undergoing transcatheter aortic valve implantation". *European Heart Journal* 34.25 (2013): 1894-1905.

21. Kempfert J., *et al*. "Aortic annulus sizing: echocardiographic versus computed tomography derived measurements in comparison with direct surgical sizing". *European Journal of Cardio-Thoracic Surgery* 42.4 (2012): 627-633.

22. Yano M., *et al*. "Aortic annulus diameter measurement: what is the best modality?" *Annals of Thoracic and Cardiovascular Surgery* 18.2 (2012): 115-120.

23. Tamburino C., *et al*. "Incidence and predictors of early and late mortality after transcatheter aortic valve implantation in 663 patients with severe aortic stenosis". *Circulation* 123.3 (2011): 299-308.

24. Abdel-Wahab M., *et al*. "Aortic regurgitation after transcatheter aortic valve implantation: incidence and early outcome. Results from the German transcatheter aortic valve interventions registry". *Heart* 97.11 (2011): 899-906.

25. Willson AB., *et al*. "Computed tomography-based sizing recommendations for transcatheter aortic valve replacement with balloon-expandable valves: Comparison with transesophageal echocardiography and rationale for implementation in a prospective trial". *Journal of Cardiovascular Computed Tomography* 6.6 (2012): 406-414.

26. Schultz CJ., *et al*. "Cardiac CT: necessary for precise sizing for transcatheter aortic implantation". *EuroIntervention* 6 (2010): G6-G13.

27. Messika-Zeitoun D., *et al*. "Multimodal assessment of the aortic annulus diameter: implications for transcatheter aortic valve implantation". *Journal of the American College of Cardiology* 55.3 (2010): 186-194.

28. Rosenhek R., *et al*. "[Identification of high risk patients with severe, but asymptomatic aortic stenosis]". *Acta Medica Austriaca* 28.1 (2001): 27-29.

Volume 2 Issue 6 April 2017