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Original Article

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Utility of Multidetector Computed Tomographic Angiography as an Alternative to Transesophageal Echocardiogram for Preoperative Transcatheter Mitral Valve Repair Planning

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ABSTRACT

BACKGROUND: Three-dimensional (3D) transesophageal echocardiogram (TEE) is the gold standard for the diagnosis of degenerative mitral regurgitation (dMR) and preoperative planning for transcatheter mitral valve repair (TMVr). TEE is an invasive modality requiring anesthesia and esophageal intubation. The severe acute respiratory syndrome coronavirus 2 pandemic has limited the number of elective invasive procedures. Multi-detector computed tomographic angiography (MDCT) provides high-resolution images and 3D reconstructions to assess complex mitral anatomy. We hypothesized that MDCT would reveal similar information to TEE relevant to TMVr, thus deferring the need for a preoperative TEE in certain situations like during a pandemic.
METHODS: We retrospectively analyzed data on patients who underwent or were evaluated for TMVr for dMR with preoperative MDCT and TEE between 2017 and 2019. Two TEE and 2 MDCT readers, blinded to patient outcome, analyzed: leaflet pathology (flail, degenerative, mixed), leaflet location, mitral valve area (MVA), flail width/gap, anterior-posterior (AP) and commissural diameters, posterior leaflet length, leaflet thickness, presence of mitral valve cleft and degree of mitral annular calcification (MAC).
RESULTS: A total of 22 (out of 87) patients had preoperative MDCT. MDCT correctly identified the leaflet pathology in 77% (17/22), flail leaflet in 91% (10/11), MAC degree in 91% (10/11) and the dysfunctional leaflet location in 95% (21/22) of patients. There were no differences in the measurements for MVA, flail width, commissural or AP diameter, posterior leaflet length, and leaflet thickness. MDCT overestimated the measurements of flail gap.
CONCLUSIONS: For preoperative TMVr planning, MDCT provided similar measurements to TEE in our study.

Keywords: Mitral valve; Multidetector computed tomography; Transesophageal echocardiography

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INTRODUCTION

Transcatheter mitral valve repair (TMVr) with the MitraClip (Abbott Vascular, Santa Clara, CA, USA) is the most commonly performed transcatheter edge-to-edge repair (TEER) procedure for mitral valve diseases in the United States.[1] The American Heart Association/American College of Cardiology (AHA/ACC) guidelines recommend transthoracic echocardiography (TTE) as the first step in determining the etiology and severity of degenerative mitral regurgitation (dMR).[2] Further, preoperative transesophageal echocardiogram (TEE) is required for anatomic screening.[2] TEE provides important information regarding the etiology of mitral regurgitation (MR), the scallop location of flail/prolapse, location and severity of regurgitant jet(s), and leaflet thickening/calcification. However, TEE is a semi-invasive diagnostic test and requires esophageal intubation and anesthesia. TEE cannot be used in patients with esophageal strictures, tumors, diverticulum, or laceration.[3] Moreover, relative contraindications to TEE include esophageal varices, symptomatic hiatus hernias, and history of radiation to head, neck or mediastinum.[3] As a result, there is a need for advanced non-invasive preoperative mitral valve imaging techniques that provide equivalent information to TEE. Cardiac magnetic resonance imaging (CMR) is an excellent diagnostic test for characterization of myocardial disease, quantification of left atrial and ventricular volumes and function along with MR severity. However, CMR is not used for the identification of mitral valve pathology or candidacy for TMVr.[2][4] Multi-detector computed tomographic angiography (MDCT) provides high-resolution images and three-dimensional (3D) reconstructions that allow for a comprehensive assessment of complex mitral anatomy. Additionally, the volumetric datasets obtained from MDCT can be subsequently manipulated into innumerable 2D planes.[5] In a previous study, MDCT was found to be inferior to TEE for detecting valve disease mechanisms but superior for detecting calcification extension.[6]

We hypothesized that MDCT could yield similar information to TEE relevant for TMVr, reducing the need for a preoperative TEE in certain instances.

METHODS

We retrospectively analyzed data on patients who underwent or were evaluated for TMVr for dMR between 2017 and 2019. The data was obtained from the hospital's dMR registry. The study included patients who underwent a multi-phase preoperative MDCT and preoperative TEE (**Figure 1**). Patients with a previous history of mitral valve repair or replacement were excluded. The clinical information was collected from the patient charts and procedural reports. Northwell Health's institutional review board approved this study. Two experienced TEE (board-certified and with more than 5 years' experience) and 2 MDCT readers (board certified and with 1–2 years' experience), blinded to patient outcomes and alternative imaging modality, analyzed the

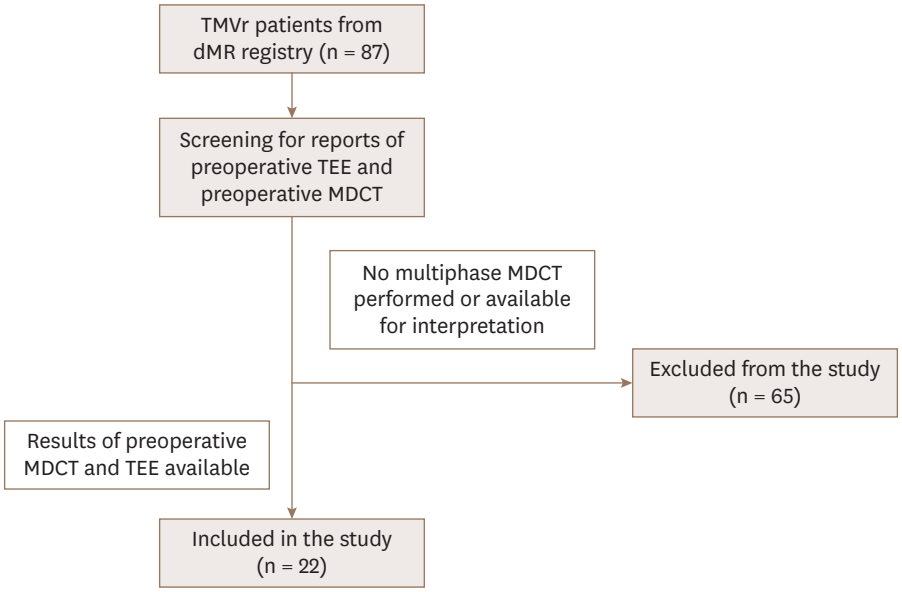

Figure 1. Flowchart showing method for inclusion of patients undergoing TMVr in the study.
dMR: degenerative mitral regurgitation, MDCT: multi-detector computed tomographic angiography, TEE: transesophageal echocardiography, TMVr: transcatheter mitral valve repair.

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following characteristics: leaflet pathology (flail, degenerative, mixed), leaflet location (A1-3/P1-3), mitral valve area (MVA), flail width/gap, anterior-posterior (AP) and commissural diameters, posterior leaflet length, maximal leaflet thickness (measured at A2/P2 region), presence of mitral valve cleft and degree of mitral annular calcification (MAC).

CT measurements

Patients were included only if they had electrocardiography-gated, multi-phase, 3D MDCT before any mitral intervention. Readers used both volume rendering (VR) 3D anatomical depiction and multiplanar reconstruction (MPR) to assess leaflet pathology, location, MVA, flail width/gap, AP and commissural diameters, posterior leaflet length, maximal leaflet thickness (measured at A2/P2 region), presence of mitral valve cleft and degree of MAC. Measurements were averaged and in cases of discrepancy between leaflet pathology/location a 3rd CT reader was asked to evaluate as an independent 'tie-breaker.' Leaflet pathology and location were assessed with a combination of VR 3D and MPR views. The dimensions of the mitral annulus were calculated with MPR CT at end-diastole. Leaflet characteristics (flail width/gap, leaflet length, and leaflet thickness) were calculated based on MPR (**Figure 2**). VR 3D imaging was used to assess if a cleft mitral leaflet was present. The degree of MAC was labeled as none, mild, moderate, or severe. Severity was calculated based on a previously published cardiac CT-based score.[7]

TEE measurements

Pre-procedural TEE was performed using Epiq CVx system with an X8-2t Live 3D transducer (Philips Medical System, Andover, MA, USA). The mitral valve was imaged and evaluated by conventional 2D with a multiplane acquisition, color, and spectral Doppler imaging as well as by 3D TEE. Mitral valve morphology, MVA at end-diastole, coaptation depth, and length, flail width, flail gap, posterior mitral leaflet length, and AP and commissural diameters were assessed and measured using 2D and 3D images with MPR using Q-Lab Software (Philips, Amsterdam, Netherlands). The presence and location of mitral leaflet clefts were evaluated using 3D imaging with color Doppler. The presence and severity of MAC were assessed qualitatively. Discrepancies in the assessment of valvular morphology and measurements were resolved by consensus.

Statistical analysis

For patient characteristics, continuous variables were reported as mean with standard deviation (SD) and compared between 2 groups using a 2-sample independent t-test or Mann–Whitney U test (non-uniform data). All statistical analyses were performed with the use of SAS software, version 9.2 (SAS Institute, Cary, NC, USA).

RESULTS

The dMR registry had 87 patients undergoing TMVr. Out of the 87 patients, 22 patients had preoperative MDCT. A total of 15 patients (68%) received TMVr, and 7 patients (32%) did not receive TMVr. The baseline characteristics of the patients included in the study is shown below in **Table 1**. The difference in the measurements of mitral valve parameters by MDCT and TEE are shown in **Table 2**.

Leaflet pathology: flail, degenerative (non-flail), or functional

Though the cohort of patients we evaluated were classified in our registry as dMR, 7 of the 22 patients were felt to be predominantly functional in etiology by review on TEE. MDCT

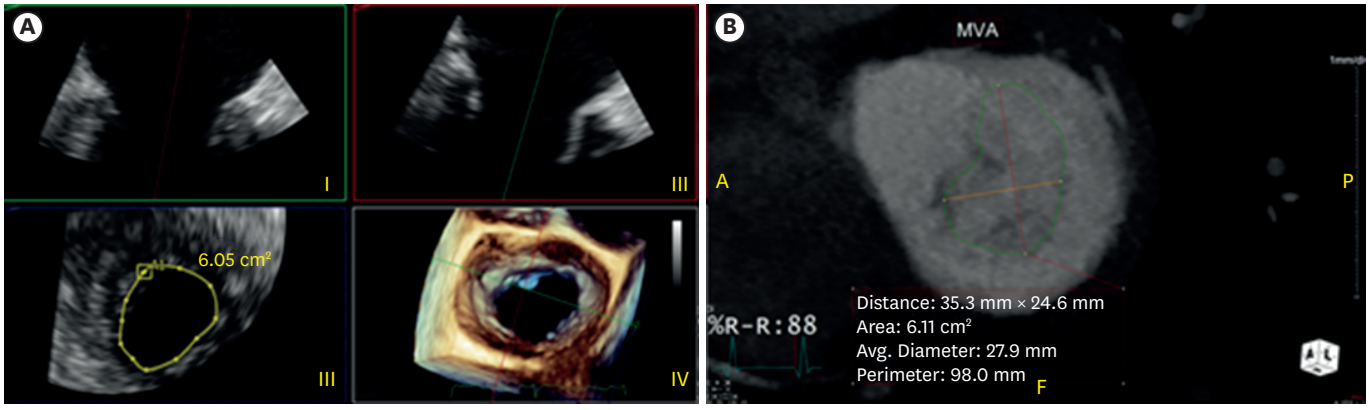

Figure 2. (A) shows the MVA measured on multiplanar reconstruction on 3-dimensional transesophageal echocardiography with MVA measured at 6.05 cm². (B) compares MVA measurement obtained on multi-detector computed tomographic angiography (short axis) with MVA measured at 6.11 cm².
MVA: mitral valve area,

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Table 1. Baseline characteristics of all patients included in the study

Variables	Values (n = 22)
Age (years)	82.32 ± 10.15
Sex (male:female)	(9:13)
Comorbidities	
Hypertension	14 (63.6)
Diabetes	7 (31.8)
Hyperlipidemia	16 (72.7)
Thyroid dysfunction	3 (13.6)
Atrial fibrillation	15 (68.2)
Coronary artery disease	11 (50)
Cerebrovascular stroke	2 (9.1)
Chronic obstructive pulmonary disease/asthma	6 (27.2)
Malignancy	3 (13.6)
Peripheral vascular disease	2 (9.1)
Previous coronary artery bypass graft	6 (27.3)
Previous percutaneous coronary intervention	3 (13.6)
Current alcohol use	4 (18.2)
Current smoker	2 (9.1)
Ejection fraction by transthoracic echocardiography	52.3 ± 9.9

Values are presented as mean ± SD or number (%).

Table 2. Differences measured on MDCT and TEE

Variables	MDCT	TEE	p-value
Mitral valve area (cm^2)	4.9 ± 1.63	4.7 ± 1.19	0.73
Flail width (mm)	8.7 ± 3.18	10.9 ± 3.22	0.14
Flail gap (mm)	8.1 ± 2.01	4.43 ± 3.1	0.01
AP diameter (mm)	31 ± 5.07	29.7 ± 5.5	0.412
Commissural diameter (mm)	38.77 ± 4.91	37.01 ± 6.5	0.32
Posterior leaflet length (mm)	13.46 ± 2.43	13.2 ± 3.2	0.77
Leaflet thickness (mm)	1.96 ± 0.551	2.1 ± 0.7	0.36

AP: anterior-posterior, MDCT: multi-detector computed tomographic angiography, TEE: transesophageal echocardiogram.

classified them correctly in 5/7 cases (71%). Of the 15 cases that were analyzed as degenerative etiology, there were 7 patients with non-flail (most commonly, prolapse) and 8 cases of flail pathology. MDCT correctly identified all 8 cases of flail pathology. **Table 3** includes each patient included in the study's MR pathology identified on TEE and MDCT.

Leaflet location

MDCT correctly predicted the dysfunctional leaflet location 95% of the time (21/22). There were 3 cases in which degenerative dysfunction occurred in more than one location. MDCT was able to determine the major dysfunction (flail) in each of them but was not able to pick up the secondary area of degeneration. In one patient with a functional MR, it appeared that there was prolapse of one segment on MDCT. In combination, MDCT was able to correctly identify the leaflet pathology and location in 77% (17/22) of patients.

Mitral valve area, AP/commissural dimensions, and MAC

There was no difference in the mean MVA measured by MDCT vs TEE respectively (4.9 ± 1.63 vs. 4.7 ± 1.19, p = 0.73) (**Figure 2**).

Table 3. Pathology of MR and degree of mitral annular calcification as determined by MDCT and TEE

Patient #	MR pathology (MDCT)	MR pathology (TEE)	MAC degree (MDCT)	MAC degree (TEE)
1	Flail	Flail	Minimal	None
2	Functional	Functional	Mild	Mild
3	Flail	Flail	Moderate	Mild
4	Non-flail DMR	Functional	None	N
5	Non-flail DMR	Non-flail DMR	Large	Mild
6	Flail	Flail	None	None
7	Non-flail DMR	Functional	Minimal	None
8	Flail	Flail	None	None
9	Flail	Flail	None	None
10	Flail	Flail	None	None
11	Functional	Functional	None	None
12	Flail	Non-flail DMR	None	None
13	Non-flail DMR	Non-flail DMR	None	None
14	Flail	Non-flail DMR	Moderate	Mild
15	Non-flail DMR	Non-flail DMR	None	None
16	Functional	Functional	Mild	Moderate
17	Functional	Functional	Mild	Mild
18	Non-flail DMR	Non-flail DMR	Mild	Mild
19	Non-flail DMR	Non-flail DMR	Severe	Mild
20	Functional	Functional	Severe	Severe
21	Flail	Flail	None	None
22	Flail	Flail	Moderate	Moderate

DMR: degenerative mitral regurgitation, MAC: mitral annular calcification, MDCT: multi-detector computed tomographic angiography, MR: mitral regurgitation, TEE: transesophageal echocardiography.

There was no difference in the measurements of AP diameter (31 ± 5.07 vs. 29.7 ± 5.5, p=0.412) and commissural diameter (38.77 ± 4.91 vs. 37.01 ± 6.5, p = 0.32) with MDCT or TEE respectively. MDCT was able to predict the degree of MAC similar to TEE in 91% of patients as shown in **Table 3**.

Flail width, flail gap, posterior leaflet length, leaflet thickness, cleft leaflet

There was no statistical difference between flail width measurements (8.7 ± 3.18 mm vs. 10.9 ± 3.22 mm) between MDCT and TEE respectively (**Figure 3**). However, MDCT over-estimated the flail gap measurement compared to TEE (8.1 ± 2.01 vs. 4.43 ± 3.1, p = 0.01).

No difference was observed for posterior leaflet length measurement (13.46 ± 2.43 vs. 13.2 ± 3.2, p = 0.77) (**Figure 4**) and leaflet thickness (1.96 ± 0.551 vs. 2.1 ± 0.7, p = 0.36) between MDCT and TEE respectively. There were 2 cases of cleft leaflet and MDCT was unable to detect a cleft leaflet in 1 of the patients.

DISCUSSION

Although a previous study has compared the mitral valve characteristics between MDCT and *intraoperative* TEE, to our

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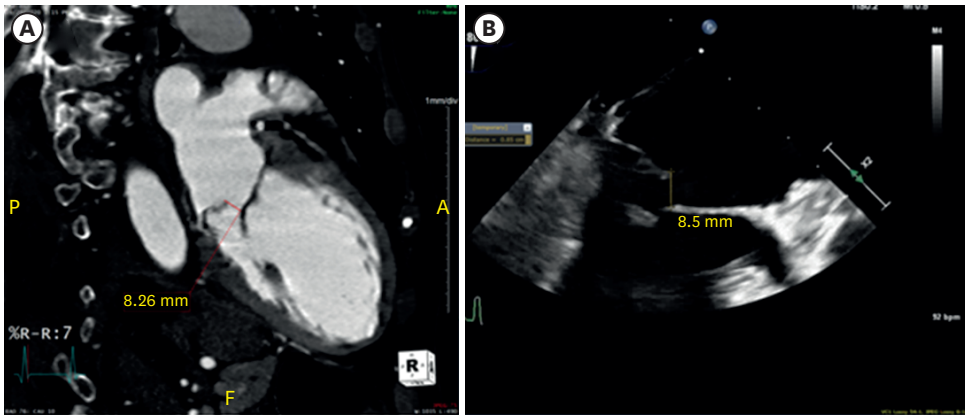

Figure 3. (A) shows flail gap measured on multi-detector computed tomographic angiography. (B) reveals measurements on 3-dimensional transesophageal echocardiography.

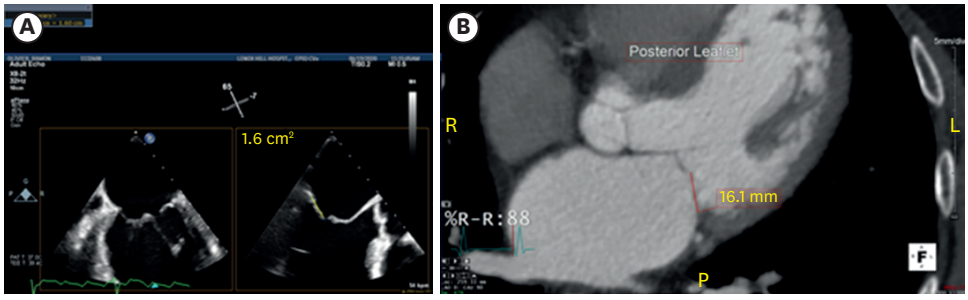

Figure 4. (A) shows an xplane of the A2/P2 segment of the mitral valve from the commissural view. The posterior leaflet measured on the long-axis view is around 1.6 cm^2 on 3-dimensional transesophageal echocardiography. (B) shows the posterior leaflet measurement on multi-detector computed tomographic angiography measured at 1.61 cm.

knowledge, this paper is the first comparison of MDCT to TEE for TMVr preoperative planning.[8] Currently available MDCT scanners, with at least 64-slice technology capable of generating images with sub millimetric spatial resolution, allow for comprehensive evaluation of complex mitral anatomy. Quantitative information including leaflet length and mitral apparatus dimensions can be obtained with MPR, while VR depicts a 3D assessment of the valve. In our study, we found that patients evaluated for TMVr with MDCT had similar findings of the mitral valve and valvular apparatus as those evaluated with TEE.

In our study, MDCT and TEE measurements for MVA, flail width, commissural diameter, AP diameter, posterior leaflet length, and leaflet thickness were not significantly different. Feuchtner et al.[9] found that MDCT can diagnose mitral valve prolapse with high accuracy. Furthermore, we found that MDCT can accurately identify the pathological leaflet scallop location, differentiate between flail and billowing leaflets, and characterize leaflet thickening. In addition, Shanks et al.[8] found that intraoperative 3D TEE had similar mitral valve geometry to MDCT (including similar measurement of the posterior leaflet length measurement). Mitral annulus measurements are usually done with MDCT, but our study found they were similar among imaging modalities. In addition, annular calcification was best assessed with MDCT in our study, and MAC severity was also comparable.

We found a discrepancy in the flail gap measurements. It is unclear why MDCT tended to overestimate the flail gap. Prior studies have felt that the 4-chamber view on MDCT resulted in an overestimation of billowing in prolapsed valves.[9] Our CT readers, therefore, used the 2- and 3-chamber reformations on MDCT to measure the flail gap, but, we still found a significant difference. We cannot rule out the possibility that MDCT is more accurate than TEE to measure flail gap, and perhaps we did not appreciate the full extent of flail on TEE. MR may be a dynamic process and the volume load (with using IV contrast) for MDCT along with the sedation given during TEE may also lead to real-life changes in the mitral pathology measurements. We therefore can't exclude the possibility that the differences found were accurate. Identification of cleft leaflet is best recognized with 3D TEE. There were 2 patients in our study with cleft leaflets, and MDCT was only able to detect the cleft in one of them. The slit-like appearance of a cleft leaflet can be difficult to see on 2D TTE or TEE. Cleft leaflets are generally identified

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on 3D TEE.[10] On MDCT, using MPR projections is difficult to assess cleft leaflets, but with VR 3D imaging we were able to identify one of the cleft leaflets. However, adjusting the window of the 3D rendered images can make the assessment of thin/soft tissue structures of the mitral leaflet a challenge, particularly clefts or pseudoclefts.

As with most imaging studies, our study is limited by inter-observer bias. Interestingly, our MDCT readers were less experienced than the TEE readers and still were able to generate similar measurements. Despite our high-quality scanner, there was systolic artifact occasionally on MDCT which may reduce accuracy. Additionally, in cases where leaflet pathology involves more than one area, interpretation of MDCT may be limited. As the study had a limited number of patients, there is a potential for selection bias. At our center, MDCT was commonly obtained in patients with complex TEER anatomy to further assess the mitral valve apparatus. Lastly, the hemodynamics may vary among TEE (done under sedation) and MDCT (performed with IV contrast volume load). MDCT and TEE were not performed on the same day in all the patients, which could lead to a variation in the mitral valve geometry in observations.

In patients where TEE is not a viable option, MDCT can provide equally important information of mitral valve apparatus for pre-operative planning. Furthermore, MDCT can then be used for adjunctive preoperative coronary evaluation. It is possible that MDCT can provide information as to whether the patient has the proper anatomy for TEER if they are contraindicated for TEE. It may be helpful in determining the course of treatment for the patient.

MDCT provides similar measurements to TEE for the comprehensive assessment of mitral valve anatomy for preoperative planning for TMVr and can be considered as an isolated preoperative diagnostic modality for planning of patients undergoing TMVr in select patients during a pandemic.

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Conflict of Interest

Chad A Kliger is a consultant and receives speaking honoraria from Edwards Lifescience and Medtronic. Luigi Pirelli is a consultant and receives speaking honoraria from Edwards Lifescience and Medtronic.
None of the other authors have anything to disclose.

Author Contributions

Conceptualization: Basman C, Wutawunashe C, Conroy J, Pirelli L, Scheinerman J, Singh V, Kliger C; Data curation: Conroy J, Kodra A; Formal analysis: Kodra A; Investigation: Ong C, Kassam Z, Conroy J, Trost B, Pirelli L; Methodology: Ong C, Kassam Z, Wutawunashe C, Conroy J, Trost B; Project administration: Kassam Z, Trost B, Mehla P; Supervision: Basman C, Mehla P, Pirelli L, Scheinerman J, Singh V; Validation: Kansara T, Kodra A, Singh V; Visualization: Kodra A, Kliger C; Writing - original draft: Kansara T, Kassam Z, Kodra A; Writing - review & editing: Basman C, Kansara T, Singh V, Kliger C.

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