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Monitoring diastolic dysfunction using a simplified algorithm in patients undergoing off-pump coronary artery bypass grafting surgery

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ABSTRACT

Context: Left ventricle diastolic dysfunction (LVDD) is gaining importance as useful marker of mortality and morbidity in cardiac surgical patients. Different algorithms have been proposed for the intraoperative grading of DD. Knowledge of the particular grade of DD has clinical implications with the potential to modify therapy, but there is a paucity of literature on the role of diastolic function evaluation during off-pump coronary artery bypass grafting (OPCABG) surgery. **Aims:** The aim of this study was to monitor changes in LVDD using simplified algorithm proposed by Swaminathan *et al*. in patients undergoing OPCABG. **Settings and Design:** The study was conducted in a tertiary care level hospital; this was a prospective, observational study. **Subjects and Methods:** Fifty consecutive patients undergoing OPCABG were enrolled. Hemodynamic and echocardiographic parameters were measured at 6 stages in every patient namely after anesthetic induction (baseline), during left internal mammary artery (LIMA) to left anterior descending (LAD) grafting (LIMA → LAD), saphenous vein graft (SVG) to obtuse marginal (OM) grafting (SVG → OM), SVG to posterior descending artery (PDA) grafting (SVG → PDA), during proximal anastomosis of SVG to aorta, and postprotamine. The patients were classified in grades of LVDD as per simplified algorithm proposed by Swaminathan *et al*. using only intraoperatively measured E and E'. **Results:** The success rate of measurement and classification of LVDD was 98.92% (277 out of 280 measurements). The grades of LVDD varied significantly as per surgical steps with maximum downgrading occurring during OM and LAD grafting. During OM grafting, none of the patients had normal diastolic function while 29% of patients exhibited restrictive pattern (Grade 3 LVDD). Patients with normal baseline LV diastolic function also exhibited downgrading during OM and LAD grafting. Postprotamine, 37% of patients with normal baseline diastolic function continued to exhibit some degree of DD. **Conclusions:** The LVDD changes dynamically during various stages of OPCABG, which can be successfully monitored with simplified algorithm.

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INTRODUCTION

Left ventricle diastolic dysfunction (LVDD) refers to an abnormality of ventricular relaxation, compliance, or filling that results in the requirement for an elevated left atrial (LA) pressure to achieve left ventricular filling.[1] Echocardiographically identified DD has been reported to be an independent predictor of

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morbidity-mortality in variety of surgeries.[2-8] As per ASE/EAE recommendations, LVDD is assessed by the integrated use of multiple echocardiographic (echo) parameters including spectral Doppler analysis of mitral inflow and pulmonary venous flow, propagation velocity (Vp) of mitral inflow, and tissue Doppler indices of mitral annular motion.[1]

To date, at least five different algorithms have been proposed for the intraoperative grading of LVDD.[1,9-12] Swaminathan *et al*. have proposed highly simplified algorithm using only intraoperatively measured E and E'. It was observed that increasingly severe grades of DD were significantly associated with reduced long-term freedom from a composite endpoint of major adverse cardiac events (MACEs) in 905 patients undergoing isolated CABG surgery.[9]

Hemodynamic management of patients undergoing off-pump coronary artery bypass grafting (OPCABG) is challenging. Transesophageal echocardiography (TEE) is extremely important monitoring tool.[13] Knowledge of the particular stage of DD has clinical implications with the potential to modify therapy.[10] However, the role of diastolic function evaluation during OPCABG surgery has not been well reported.

The aim of this study was to monitor changes in LVDD using simplified algorithm proposed by Swaminathan *et al*. in patients undergoing OPCABG.

SUBJECTS AND METHODS

Fifty-one consecutive patients undergoing OPCABG were enrolled in this study. One patient was converted to on-pump CABG in view of hemodynamic instability while doing obtuse marginal (OM) grafting. The final analysis included fifty patients. The review board approved this study with waiver off to take separate consent. All patients underwent surgery by midline sternotomy. Standardized anesthesia protocol consisted of general anesthesia with midazolam, fentanyl, and propofol. Vecuronium was used as muscle relaxant. Anesthesia was maintained with boluses of fentanyl, midazolam, and isoflurane as inhalational agent. Monitoring consisted of arterial blood pressure measured by femoral arterial catheter and pulmonary artery catheter inserted by the right internal jugular vein before induction. Surgical steps consisted of midline sternotomy, harvesting of the left internal mammary artery (LIMA) and saphenous vein grafts (SVGs), adequate heparinization (target activated clotting time >300 s), LIMA to left anterior descending (LAD) grafting, and then as per severity of the coronary artery lesion remaining grafts on OM and posterior descending artery (PDA). After the grafting heparin was reversed with protamine, hemostasis was achieved and wound was closed in layers. A single surgical team performed all surgeries.

A TEE probe was gently inserted after induction and TEE images acquired and stored in Acuson X 500 Siemens Echo Machine. Hemodynamic and echo parameters were measured at 6 stages in every patient namely after anesthetic induction (baseline), during LIMA to LAD grafting (LIMA → LAD), SVG to OM grafting (SVG → OM), SVG to PDA grafting (SVG → PDA), during proximal anastomosis of SVG to aorta, and postprotamine. All the measurements were made after hemodynamic stability was achieved, for example, the measurements were made after passing intracoronary shunt when the distal anastomosis was performed. When more than one graft was performed in a territory the values were averaged. All measurements were made in real-time and stored for analysis.

The details of echo measurements are as follows: Transmitral Doppler consisted of measurement of E-wave velocity, A-wave velocity, E/A ratio, and deceleration time performed in the mid-esophageal 4-chamber view. A pulsed wave (PW) Doppler sample volume was placed at the mitral leaflet tips. Spectral recordings were made at end-expiration, when feasible, at a sweep speed of 50–100 mm/s depending on heart rate. Measurements were not averaged over several cycles, but the most representative waves were chosen for measurements. To ensure proper alignment, color flow Doppler was performed before PW Doppler interrogation to visualize the direction of blood flow since the direction of mitral inflow may vary depending on the underlying pathology and varying position of the heart. Mitral annular motion was assessed in the mid-esophageal 4-chamber view with the Doppler beam aligned as parallel as possible to the axis of motion of the cardiac tissue being measured. A sample volume was placed on the lateral annulus within 1 cm of the mitral leaflet insertion sites. The velocity scale was reduced to 20 cm/s from baseline, and the sweep speed is adjusted to approximately 50–100 mm/s; most representative waves were chosen for measurements.

The patients were classified in grades of LVDD as per simplified algorithm proposed by Swaminathan *et al*. [Figure 1].

RESULTS

Baseline characteristics of fifty patients are as shown in Table 1.

An echo measurement for DD by simplified algorithm at baseline was possible in all fifty patients. In 49 patients undergoing LIMA → LAD, echo measurement was possible in all patients; OM was done in 43 patients and PDA grafting was done in 41 patients and echo measurement was possible in 42 and forty patients, respectively; in one patient, echo measurement was not possible at proximal grafting; echo measurement was successfully carried out in all 50 patients postprotamine. Thus, the success rate of measurement and classification of DD was 98.92% (277 out of 280 measurements). The main reason for unsuccessful measurement was inability to obtain good mitral annular motion.

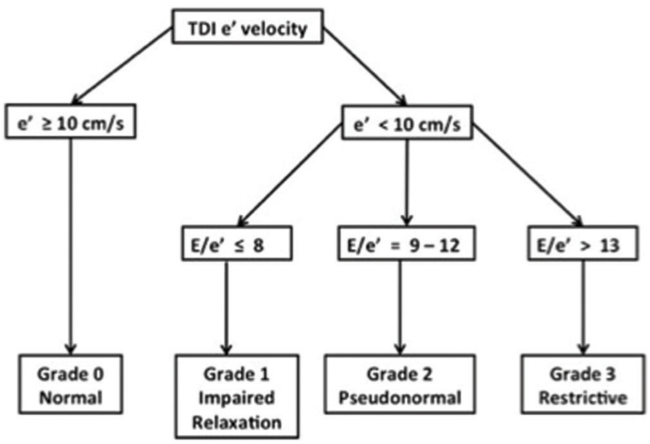

Figure 1: Simplified algorithm proposed by Swaminathan *et al*

The hemodynamic parameters at various stages of surgery are as shown in Table 2.

The echo parameters at various stages of surgery are as shown in Table 3.

The patients' grades of DD as per various stages of surgery are as shown in Table 4 and Figure 2. To describe the dynamic nature of this change, "motion charts" using Google Spreadsheets were used [Videos 1-4]. A motion chart is a dynamic bubble chart which allows efficient and interactive exploration and visualization of longitudinal multivariate data. The grades of DD varied significantly as per surgical steps with maximum downgrading occurring during OM and LAD grafting. During OM grafting, none of the patients had normal diastolic function while 29% of patients exhibited restrictive pattern (Grade 3 LVDD).

Patients with normal baseline LV diastolic function also exhibited downgrading during OM and LAD grafting. Postprotamine, 37% of patients with normal baseline diastolic function continued to exhibit some degree of DD as shown in Figure 3 and Video 2.

A representative patient's transmitral PW Doppler and TDI are shown in Figures 4-15.

Table 1: Baseline characteristics of 50 patients

Parameter	Values
Mean age (years)±SD	59±9
Female (%)	6 (12)
Mean height (cm)±SD	164±8
Mean weight (kg)	65
Hypertension (%)	34 (68)
Diabetes mellitus	17 (34)
Mean creatinine (mg%)±SD	1.01±0.2
Mean ejection fraction (%)	51±11
History of myocardial infarction (%)	13 (26)
Mean number of coronary arteries diseased (IQR)	2.74 (2-3)
Mean grafts performed (IQR)	3.29 (3-4)

SD: Standard deviation, IQR: Interquartile range

Table 2: The hemodynamic parameters at various stages of surgery

	Baseline	LIMA→LAD	SVG→OM	SVG→PDA	Proximal anastomosis	Postprotamine
HR (±SD)	78±12	79±13	85±14	82±13	81±12	85±13
SBP (±SD)	114±12	104±12	99±13	106±12	98±12	105±9
DBP (±SD)	65±9	60±9	58±12	62±9	54±10	58±10
SPAP (±SD)	21±5	25±5	26±6	22±5	18±5	21±4
DPAP (±SD)	10±3	13±3	13±4	11±4	7±4	103
Inotrope use (%)	0 (0)	12 (24.4)	16 (37.4)	10 (24.3)	9 (18.36)	9 (18)

HR: Heart rate (/min), SBP: Systolic blood pressure (mm of Hg): DBP: Diastolic blood pressure (mm of Hg), SPAP: Systolic pulmonary artery pressure (mm of Hg), DPAP: Diastolic pulmonary artery pressure (mm of Hg), SD: Standard deviation, LIMA: Left internal mammary artery, LAD: Left anterior descending, SVG: Saphenous vein grafts, OM: Obtuse marginal, PDA: Posterior descending artery

Table 3: The echocardiographic parameters at various stages of surgery

	Baseline	LIMA→LAD	SVG→OM	SVG→PDA	Proximal anastomosis	Postprotamine
E (±SD)	59±14	52±14	51±16	50±14	51±13	54±15
A (±SD)	55±15	58±15	61±20	60±16	54±17	56±15
E/A (±SD)	1.1±0.4	0.95±0.3	0.93±0.4	0.87±0.3	0.97±0.2	1.02±0.4
E'(±SD)	9.58±2.6	6.55±1.5	5.23±1.4	7.17±1.9	8.14±2.06	8.18±1.9
A' (±SD)	7.9±2	6.67±2	5.21±2	7.77±2	8.28±2	8.04±2
S' (±SD)	7.96±2	6.55±2	5.97±2	6.99±2	7.44±2	7.24±2
E/E' (±SD)	6.42±1.9	8.31±2.6	10.2±3.21	7.23±2.3	6.60±2.0	6.97±1.8

SD: Standard deviation, LIMA: Left internal mammary artery, LAD: Left anterior descending, SVG: Saphenous vein grafts, OM: Obtuse marginal, PDA: Posterior descending artery

Table 4: Patients' grades of diastolic dysfunction as per various stages of surgery

Grade	Baseline (*n*=50) (%)	LIMA→LAD (*n*=49) (%)	SVG→OM (*n*=42) (%)	SVG→PDA (*n*=40) (%)	Proximal anastomosis (*n*=49) (%)	Postprotamine (*n*=50) (%)
0	19 (38)	01 (2)	00	05 (12)	13 (26)	15 (30)
1	21 (42)	20 (41)	12 (29)	21 (53)	26 (53)	22 (44)
2	10 (20)	27 (55)	18 (42)	14 (35)	10 (21)	13 (26)
3	00	01 (2)	12 (29)	00	00	00

SD: Standard deviation, LIMA: Left internal mammary artery, LAD: Left anterior descending, SVG: Saphenous vein grafts, OM: Obtuse marginal, PDA: Posterior descending artery

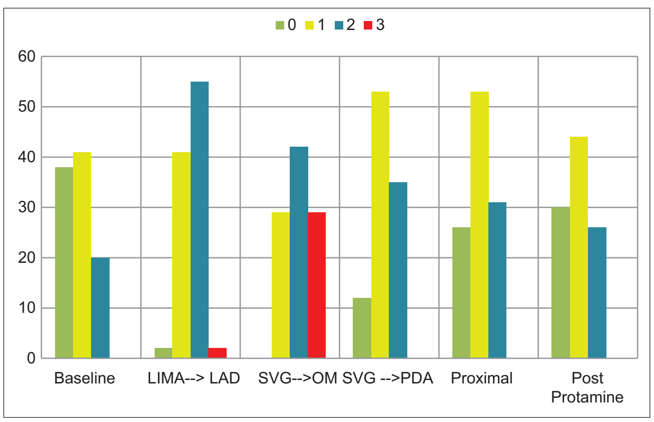

Figure 2: The patients' grades of diastolic dysfunction as per various stages of surgery

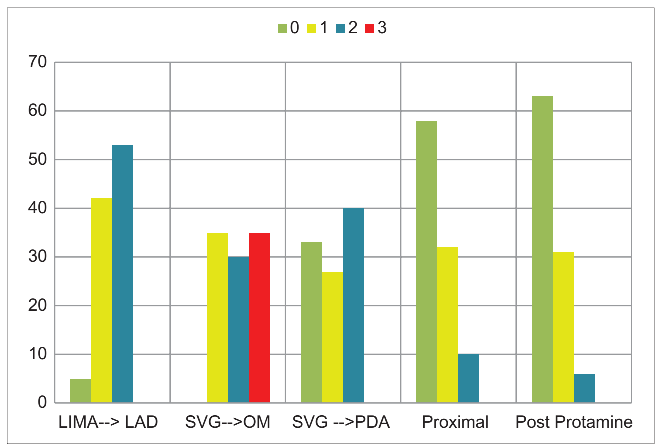

Figure 3: Changes in grades of diastolic dysfunction in baseline normal function

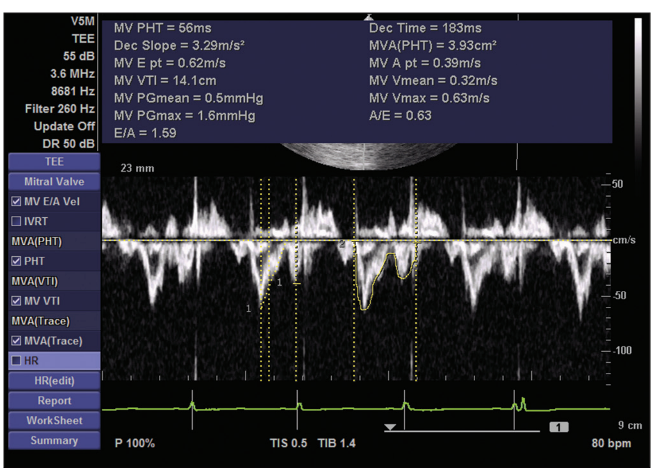

Figure 4: Transmitral pulsed wave Doppler at baseline

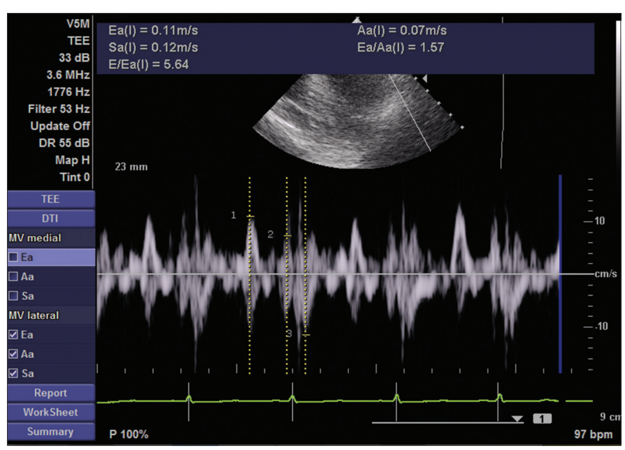

Figure 5: Tissue Doppler imaging at baseline

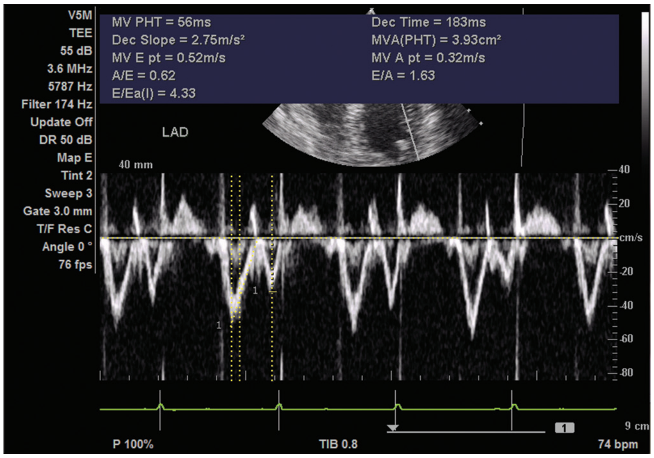

Figure 6: Transmitral pulsed wave Doppler at left internal mammary artery → left anterior descending

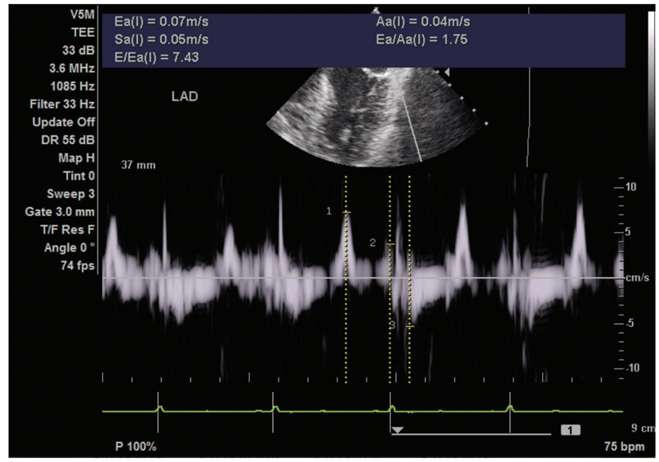

Figure 7: Tissue Doppler imaging at left internal mammary artery → left anterior descending

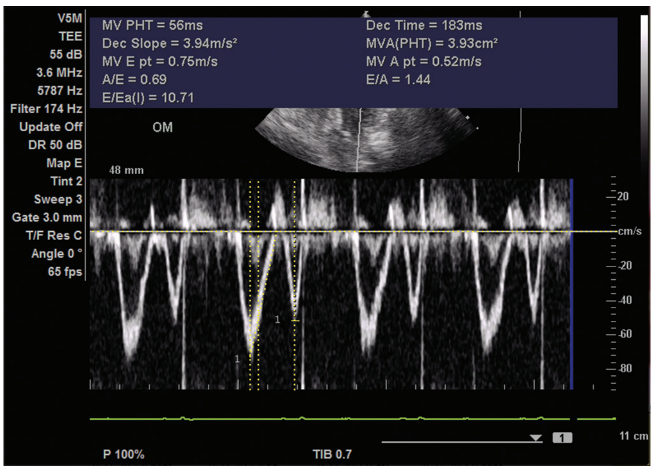

Figure 8: Transmitral pulsed wave Doppler at saphenous vein graft → obtuse marginal

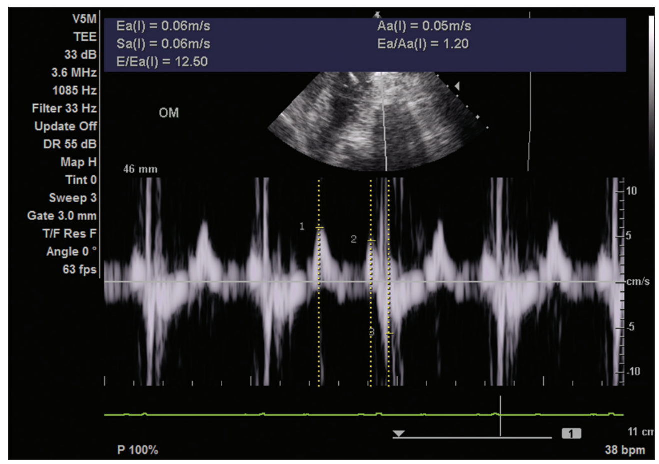

Figure 9: Tissue Doppler imaging at saphenous vein graft → obtuse marginal

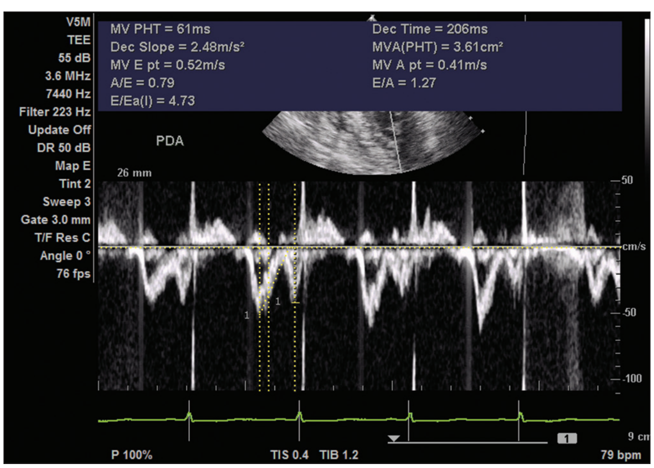

Figure 10: Transmitral pulsed wave Doppler at saphenous vein graft → posterior descending artery

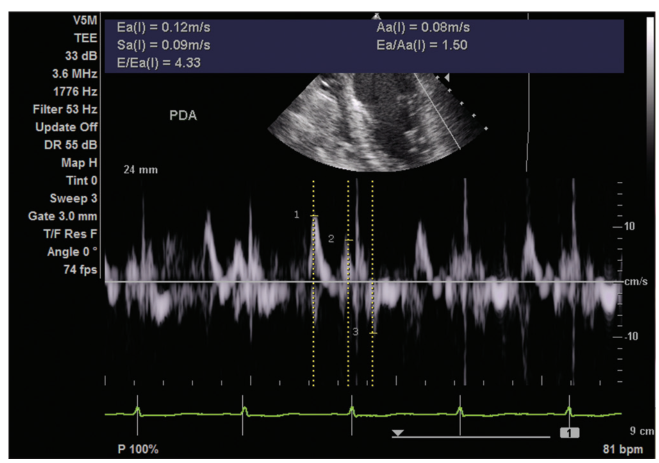

Figure 11: Tissue Doppler imaging at saphenous vein graft → posterior descending artery

DISCUSSION

The main findings of this observational study are LVDD changes dynamically in patients undergoing OPCABG as per surgical stages with maximum downgrading occurring during OM and LAD grafting. This can be successfully classified with the help of a simplified algorithm proposed by Swaminathan

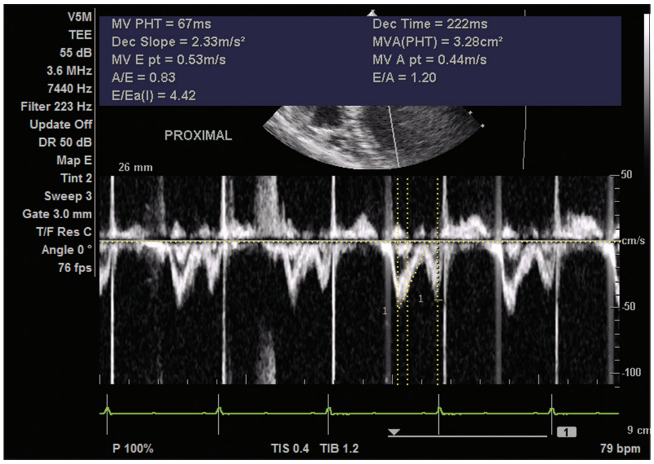

Figure 12: Transmitral pulsed wave Doppler at proximal

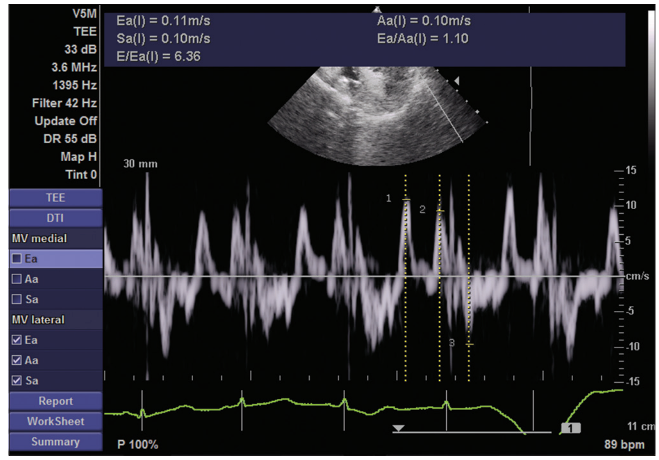

Figure 13: Tissue Doppler imaging at proximal

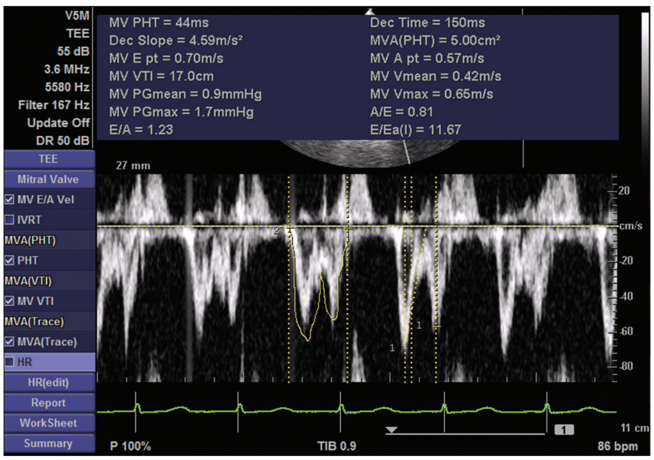

Figure 14: Transmitral pulsed wave Doppler at postprotamine

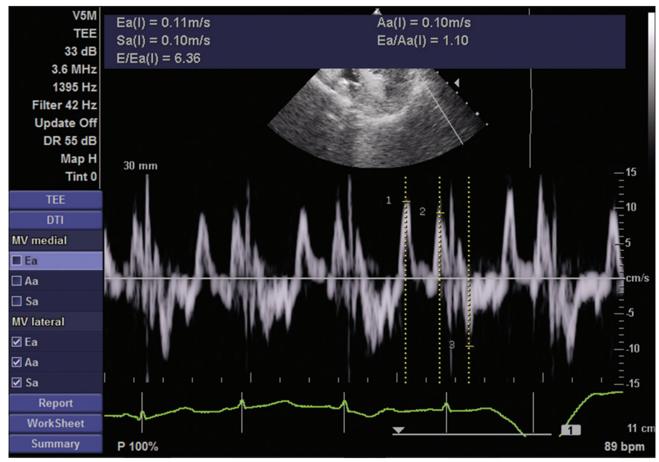

Figure 15: Tissue Doppler imaging at postprotamine

et al. in 98.92% (277 out of 280) measurements. Even in patients with normal baseline diastolic function, there is a downgrading of LVDD, particularly during OM grafting, around one-third of patients with normal baseline diastolic function continued to exhibit some degree of DD postprotamine.

It is now well established that diastolic function, just as systolic function, has clinical, therapeutic, and prognostic implications. An observational study by Afilalo *et al*. documented that preoperative DD as evidenced by restrictive filling was a strong predictor of mortality with odds ratio of 2.96.[2] Bernard *et al*. reported that abnormal diastolic filling patterns were frequently observed particularly in patients with altered LV function. DD present before cardiopulmonary bypass (CPB) was associated with an increased risk of difficulty in separation from CPB and vasoactive support in the Intensive Care Unit.[3] Same group of investigators from Montreal, Canada, in another study reported that moderate and severe LVDDs and right ventricular DD could be identified with very good reproducibility, and both degrees of diastolic dysfunction were associated with difficulty in separation from CPB.[12] New or worsened DD after CABG surgery is associated with an increased incidence of postoperative atrial fibrillation.[4] There is evidence suggesting that moderate to severe DD in patients with aortic stenosis is an independent predictor of late mortality after valve replacement.[5] The presence of perioperative DD as assessed with Vp is an independent predictor of postoperative congestive heart failure and prolonged length of stay after major vascular surgery.[6] Despite this, a recent multinational survey on TEE suggests that only 46% of academic centers currently perform an assessment of diastolic function routinely during cardiac surgery.[14]

There is evidence supporting that preoperative DD is associated with poor outcome in patients undergoing OPCABG. In a large study of 1048 patients undergoing OPCABG, the authors evaluated the prognostic implications of preoperative estimated LV filling pressure, assessed by E/E' ratio which was an independent predictor of 30-day and 1-year MACE. The recommended measurements of E/E' may assist in preoperative risk stratification of these patients.[7] In another study, E/E' ratio >15 was a significant predictor of composite endpoints of postoperative morbidity.[8] Another study suggested that even in patients with preserved systolic LV function, patients with E/E'>15 were more prone to undergo a significant decrease in cardiac output during OPCAB, which did not return to baseline level after completion of grafting.[15] In contrast to preoperative dysfunction, our study has evaluated intraoperative stage wise changes in DD in patients undergoing OPCABG. About one-third of patients with normal baseline function did not return to normal, but whether these changes in DD is associated with poor outcome remains to be evaluated.

Knowledge of the particular stage of DD has clinical implications with the potential to modify therapy.[10,16,17] During the impaired relaxation phase, the mainstay of treatment is increasing preload and reducing heart rate to allow for adequate LV filling. Patients in the decreased compliance stage have an increased LA pressure at baseline, i.e., preload intolerant, thus requiring a careful perioperative fluid management and the judicious use of diuretics. Furthermore, they may require a higher aortic pressure to increase the coronary perfusion pressure owing to an increased LVEDP. The appreciation of these fine differences between the stages of DD can further optimize perioperative management and possibly improve outcome.

To date, at least five different algorithms have been proposed for the intraoperative grading of DD.[1,9-12] Some of these algorithms are very complex to be used in the busy environment of operating rooms; some are not validated while using some of these guidelines result in inability to classify a large proportion of patients. A simplified approach is highly desirable intraoperatively owing to the limited time frame for TEE examination. However, any grading system, regardless of simplicity, is irrelevant unless it provides prognostic information by identifying those at risk of adverse outcomes.

The simplified algorithm suggested by Swaminathan *et al*.[9] fulfills most of these criteria. It is simple, can be rapidly used in intraoperative period, and is validated in cardiac surgical population. Using the highly simplified algorithm using only intraoperatively measured E and E', increasingly severe grades of DD were significantly associated with reduced long-term freedom from a composite endpoint of MACE in 905 patients undergoing isolated CABG surgery.[9] In contrast, strict application of a comprehensive algorithm in keeping with ASE guidelines to grade DD provided no clear association between grade of dysfunction and MACE-free survival. In our study also, we could assign a particular grade of DD to around 98% patients during all stages of OPCABG.

The hemodynamic management during OPCABG is challenging. It is advocated that TEE should be used in all patients undergoing OPCBAG.[13,18] Gurbuz *et al*.[19] looked at the effect of intraoperative TEE on OPCAB patients specifically. Seven hundred forty-four OPCAB patients who had intraoperative TEE were retrospectively studied. They found that TEE revealed previously undiagnosed intracardiac pathology in 1.3% of patients, with major modification in a surgical procedure. An intra-aortic balloon pump was placed in 3.2% of patients at the start of the procedure after intraoperative TEE revealed severe left ventricular dysfunction that had previously been underappreciated. Severe aortic atheromatous disease was found in 4.1% of patients, and all of these patients had a change in surgical plan to a no-touch aorta technique with complete arterial revascularization. In another series of 500 patients undergoing OPCABG, Mishra *et al*.[20] observed that was development of new regional wall motion abnormalities in 59.2% and a decrease in global left ventricular functions in 61.2%. Obstruction of the right ventricular outflow tract was observed on TEE at various stages during vertical displacement of the heart. The authors concluded that the use of intraoperative TEE was valuable in enhancing the safety of the procedure.

However, intraoperative patterns of change in echocardiographic patterns of diastolic function, as well as their clinical significance, remain poorly defined. We could describe a particular pattern of DD using this simplified algorithm. Maximum DD occurred during OM and LAD grafting. None of the patients had normal diastolic function during OM grafting. Two-thirds of the patients with normal baseline function returned to normal values postprotamine. It remains to be ascertained whether applying particular therapy can improve outcomes depending on the grade of DD.

There can be various explanations to these changes. Tachycardia and rhythm disturbances may occur due to hypovolemia, anemia, or electrolyte imbalances and may impair left ventricular filling.[17] Patients may develop mitral regurgitation due to positioning of the heart particularly while performing OM grafting.[21] DD can be an early marker of ischemia. Myocardial ischemia affects the processes underlying systolic inactivation, that is, calcium extrusion from the cytosol and cross-bridge detachment, and will result in delayed relaxation. Adequate relaxation depends on systolic events such as timing, velocity, and synchronicity of contraction, increased left ventricular afterload, and wall stress, and left ventricular dyssynchronous contraction results in delayed and incomplete relaxation.[17]

This study has some notable limitations. The study is limited to only intraoperative period; we do not have similar preoperative data or postoperative follow-up. A study with postoperative follow-up with larger patient population undergoing OPCABG is highly desirable. This study consisted of a limited number of patients operated by a single surgical team; varying results are highly possible with different patients' population and expertise.

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Nil.

Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. Nagueh SF, Appleton CP, Gillebert TC, Marino PN, Oh JK, Smiseth OA, *et al*. Recommendations for the evaluation of left ventricular diastolic function by echocardiography. J Am Soc Echocardiogr 2009;22:107-33.
2. Afilalo J, Flynn AW, Shimony A, Rudski LG, Agnihotri AK, Morin JF, *et al*. Incremental value of the preoperative echocardiogram to predict mortality and major morbidity in coronary artery bypass surgery. Circulation 2013;127:356-64.
3. Bernard F, Denault A, Babin D, Goyer C, Couture P, Couturier A, *et al*. Diastolic dysfunction is predictive of difficult weaning from cardiopulmonary bypass. Anesth Analg 2001;92:291-8.
4. Ashes CM, Yu M, Meineri M, Katznelson R, Carroll J, Rao V, *et al*. Diastolic dysfunction, cardiopulmonary bypass, and atrial fibrillation after coronary artery bypass graft surgery. Br J Anaesth 2014;113:815-21.
5. Gjertsson P, Caidahl K, Farasati M, Odén A, Bech-Hanssen O. Preoperative moderate to severe diastolic dysfunction: A novel Doppler echocardiographic long-term prognostic factor in patients with severe aortic stenosis. J Thorac Cardiovasc Surg 2005;129:890-6.
6. Matyal R, Hess PE, Subramaniam B, Mitchell J, Panzica PJ, Pomposelli F, *et al*. Perioperative diastolic dysfunction during vascular surgery and its association with postoperative outcome. J Vasc Surg 2009;50:70-6.
7. Lee EH, Yun SC, Chin JH, Choi DK, Son HJ, Kim WC, *et al*. Prognostic implications of preoperative E/e' ratio in patients with off-pump coronary artery surgery. Anesthesiology 2012;116:362-71.
8. Jun NH, Shim JK, Kim JC, Kwak YL. Prognostic value of a tissue Doppler-derived index of left ventricular filling pressure on composite morbidity after off-pump coronary artery bypass surgery. Br J Anaesth 2011;107:519-24.
9. Swaminathan M, Nicoara A, Phillips-Bute BG, Aeschlimann N, Milano CA, Mackensen GB, *et al*. Utility of a simple algorithm to grade diastolic dysfunction and predict outcome after coronary artery bypass graft surgery. Ann Thorac Surg 2011;91:1844-50.
10. Mahmood F, Jainandunsing J, Matyal R. A practical approach to echocardiographic assessment of perioperative diastolic dysfunction. J Cardiothorac Vasc Anesth 2012;26:1115-23.
11. Matyal R, Skubas NJ, Shernan SK, Mahmood F. Perioperative assessment of diastolic dysfunction. Anesth Analg 2011;113:449-72.
12. Denault AY, Couture P, Buithieu J, Haddad F, Carrier M, Babin D, *et al*. Left and right ventricular diastolic dysfunction as predictors of difficult separation from cardiopulmonary bypass. Can J Anaesth 2006;53:1020-9.
13. Kapoor PM, Chowdhury U, Mandal B, Kiran U, Karnatak R. Trans-esophageal echocardiography in off-pump coronary artery bypass grafting. Ann Card Anaesth 2009;12:167.
14. Dobbs HA, Bennett-Guerrero E, White W, Shernan SK, Nicoara A, Mauricio Del Rio J, *et al*. Multinational institutional survey on patterns of intraoperative transesophageal echocardiography use in adult cardiac surgery. J Cardiothorac Vasc Anesth 2014;28:54-63.
15. Shim JK, Choi YS, Chun DH, Hong SW, Kim DH, Kwak YL. Relationship between echocardiographic index of ventricular filling pressure and intraoperative haemodynamic changes during off-pump coronary bypass surgery. Br J Anaesth 2009;102:316-21.
16. McIlroy DR, Lin E, Durkin C. Intraoperative

transesophageal echocardiography: A critical appraisal of its current role in the assessment of diastolic dysfunction. J Cardiothorac Vasc Anesth 2015;29:1033-43.
17. Nicoara A, Whitener G, Swaminathan M. Perioperative diastolic dysfunction: A comprehensive approach to assessment by transesophageal echocardiography. Semin Cardiothorac Vasc Anesth 2013;18:218-236.
18. Morganstern J, Kanchuger M. Pro: All off-pump coronary artery bypass graft surgeries should include intraoperative transesophageal echocardiography assessment. J Cardiothorac Vasc Anesth 2008;22:625-8.
19. Gurbuz AT, Hecht ML, Arslan AH. Intraoperative transesophageal echocardiography modifies strategy in off-pump coronary artery bypass grafting. Ann Thorac Surg 2007;83:1035-40.
20. Mishra M, Malhotra R, Mishra A, Meharwal ZS, Trehan N. Hemodynamic changes during displacement of the beating heart using epicardial stabilization for off-pump coronary artery bypass graft surgery. J Cardiothorac Vasc Anesth 2002;16:685-90.
21. Couture P, Denault A, Limoges P, Sheridan P, Babin D, Cartier R. Mechanisms of hemodynamic changes during off-pump coronary artery bypass surgery. Can J Anaesth 2002;49:835-49.