Original Article

Indian Journal of Anaesthesia and Analgesia
Volume 4 Number 2, April - June 2017 (Part–2)
DOI: http: / / dx.doi.org / 10.21088 / ijaa.2349.8471.4217.25

Right Ventricular Systolic Function in Off Pump Coronary Artery Bypass (OPCAB) and Its Measurement by Tricuspid Annular Plane Systolic Excursion

Harish R.*, Ramesh Srigiri, Mahesh Vakamudi**, Ranjith B. Karthekeyan****

Abstarct

Background & Aim: Right ventricle function significantly decreases after coronary artery bypass surgery; as one of the likely causes, such a condition is attributed to the use of cardiopulmonary pump (CPB). Because nowadays there is a tendency toward increasing use of off-pump coronary artery bypass (OPCAB) surgery, this study was conducted to evaluate the right ventricle function perioperatively by TAPSE and simultaneously assess the influence of RV systolic function on the perioperative outcome in terms of duration of ventilation, inotropic support, length of intensive care unit stay etc. in the perioperative period in off pump coronary artery bypass grafting. *Methods:* This Prospective observational study was conducted on 54 triple vessel disease patients elective OPCABG surgery. RV systolic function assessed by measuring Tricuspid Annular Plane Systolic Excursion(TAPSE) by both TEE & Transthoracic ECHO. *Results:* RVEF is most used index of RV contractility normal RVEF – 40-76%. Statistically significant improvement of TAPSE values observed post grafting. The improvement of TAPSE values are observed irrespective of whether RCA or PDA grafted or not. In this study, improved TAPSE values did not significantly improve periop outcome in elective OP CABG patients in terms of length of ICU stay, inotropic support and duration of ventilation. *Conclusions:* The RV systolic function can be assessed routinely in perioperative setting by using TAPSE with relative easy. There is significant improvement in RV systolic function post grafting in elective OFFPUMP CABG surgeries. The improvement of RV systolic function in irrespective of right coronary artery grafting. The improvement of RV systolic function did not influence perioperative outcome significantly. Limitations of this study may be small sample size, Intra observer variations associated with echocardiography.

Keywords: Right Ventricle Function; Off-Pump Coronary Artery Bypass Surgery (OPCAB Surgery); Tricuspid Annular Plane Systolic Excursion.

Introduction

Over the past few decades, there has been a revived interest in the role of right ventricular function in cardiovascular health. Majority of the data in cardiology focused on left ventricular structure and function, the appreciation of the importance of RV function has, nevertheless, been steadily increasing. Right ventricular (RV) function may be impaired in pulmonary hypertension (PH), congenital heart disease (CHD), and coronary artery disease and in patients with left-sided heart failure (HF) or valvular heart disease.

Evaluation of RV structure and function in patients with cardiopulmonary disorders is an essential component of clinical management. Reduced right ventricular function is a common finding in coronary artery bypass graft surgery (CABG) which can cause heart failure and increase mortality after surgery [1-4]. The underlying mechanism may attributed to different causes such as intraoperative ischemia, intraoperative myocardial damage and the use of cardiopulmonary pump (CPB) [5].

Author's Affiliation:
*Dept. of Cardiac Anesthesia, Narayana Medical College & Hospital, Nellore, Andhra Pradesh.
**Department of Anaesthesiology and Critical Care, Sri Ramachandra Medical College and Research Institute, Sri Ramachandra University, Chennai.

Corresponding Author:
Harish R., Dept. of Cardiac Anesthesia, Narayana Medical College & Hospital, Nellore - 524003, Andhra Pradesh.
E-mail: drharish78@gmail.com

Received on 17.02.2017
Accepted on 04.03.2017

Some studies have reported that the echocardiographic right ventricular dysfunction can last up to even 1 year after CABG [2,6]; nevertheless, due to improved levels of exercise stress test, some studies have considered a minor clinical value for such disorders [2].

Off-pump coronary artery bypass surgery (OPCAB) is accepted as a procedure which allows the surgeon to perform CABG on a beating heart without aortic cannulation and clamp and it has been proved as effective way whose long-term patients survival rate do not differ with that of on-pump CABG [7,8].

Echocardiographic assessment of left ventricular function is simple, however due to the complex anatomy of the right ventricle; it is difficult to evaluate its performance by echocardiography. In clinical practice, echocardiography is the mainstay of evaluation of RV structure and function. Tricuspid Annular Plane Systolic Excursion by 2D echocardiography has been proposed as a reliable objective index of RV function.

The importance of RV function in patients undergoing cardiac surgery has been recognized for several years. Although not included in previous risk assessment scores for cardiac surgical patients, right ventricular (RV) function has been associated with patient outcome in a variety of clinical scenarios. Many studies in the hemodynamically unstable postoperative cardiac patients showed that RV systolic dysfunction was associated with an increased risk of mortality and morbidity [9]. Very few studies in literature evaluated Right Ventricular systolic dysfunction and its influence on the postoperative out come in patients undergoing coronary artery

Off pump Coronary Artery Bypass Grafting surgery is major evolution in cardiac surgery in the last ten years it has reduction in the use of cardiopulmonary bypass and a reduction in the invasiveness of surgical approach [10].

As there is no data on RV systolic function and its influence on the perioperative out come especially in off pump Coronary Artery Bypass Grafting (OPCABG), the present study designed in evaluating RV systolic function by Tricuspid annular plane systolic excursion (TAPSE) and its influence in the perioperative period .

Materials and Methods

This prospective observational study on 60 patients with triple vessel disease for elective OPCAB surgery in our cardiac care centre between October 2009 to March 2010. The main criterion for the inclusion was the electiveness of the surgery. Exclusion criteria were: patients with known chronic obstructive pulmonary disease (COPD) and, patients with associated valvular lesions(aortic and mitral), renal failure (serum creatinine >2.0 mg/dl), pre existing neurological stroke, patients in whom surgery planned to do on cardo pulmonary bypass pump, patients undergoing concomitant aneurysmectomy, and redo CABG. The study taken ethical approval from the instutional ethics committee.

After obtaining their written informed consent, the preoperative echocardioagram performed by the cardialogist 2-3 days prior to surgery preoperative left ventricle (LV) ejection fraction (caliculated by simpson's method), severity of pulmonary artery hypertension , degree of tricuspid regurgitation and area of myocardial infarcts (hyokinetic and or akinetic segments) are recorded. A 16-segment model was used for the LV, and a 5-segment model was used for the RV (inferior, posterior, free, apex, and RV outflow tract). The number of significant vessel narrowing was noted from coronary angiogram. A significant narrowing of the coronary artery was defined as a ≥70% reduction of cross-sectional area.

In the operation theatre under standard institution protocol pre induction monitors attached before securing intravenous line and arterial line. All the patients had pulmonary artery catheter inserted before induction.Central venous pressure and pulmonary capillary wedge pressure were recorded as base line filling pressures. Later filling pressures were recorded at the time of obtaining ultra sound images. Standard anesthesia conditions applied to all patients.After intubation, TEE probe was passed into mid esophagus for assessment of rifht ventricular systolic function. Echocardiographic imaging was performed using Gemedical Systems Vivid 7 Dimensions 5 MHz transducer (6T GE Medical Systems) with attached three lead ECG. The RV systolic function was assessed by measuring Tricuspid Annular systolic excursion plane using M-Mode To measure baseline TAPSE value images are obtained by placing the M MODE curser through the lateral tricuspid annulus in real time using mid esophageal four chamber 0 -10 degrees. The caliper was placed from the leading edge of end diastolic to the leading edge of end systole to measure the total displacement of tricuspid annulus towards the apex. That end-diastolic measurements are taken at the onset of the q-wave and end-systolic measurements at the end of the T-wave. 5-7 beats were recorded. Values represented the average of three beats.

Similarly next values of TAPSE are obtained after sternotomy.

Surgery was done by the same surgeon for all the patients. Intraoperatively the number of patients who has undergone either right coronary artery or posterior descending artery grafting are noted. The inotropes were started based on hemodynamic variables, clinical status and echocardiographic assessment.

Postoperatively patients are shifted to the ICU for further management. Once the patient meets the extubation criteria, patients are extubated and duration of ventilation recorded. Transthoracic echocardiogram was performed by using 4MHz probe (4S GE Medical Systems) apical four chamber view was used to assess the images for measuring the TAPSE value.the images are recorded on day 1(on the da y of surgery), 2 and 3 of post operative period in the intensive care unit. Left ventricular ejection fraction for all the patients were recorded by Simpson's method on the third post operative day Patients were discharged to the ward usually on the third postoperative day.

Post operatively number of patients on 1) Ventilator more than 24 hrs, 2) Inotropic support inotropes in the intaoperative or postoperative, 3) duration of the ICU for more than three days, and incidence of adverse events like arrythmias, new onset of ST elevation, reintubation, renal failure (serum creatinine >2) stroke and death are noted.

All the TAPSE values were measured by another observer who was blinded from the clinical and hemodynamic variables to avoid intraobserver bias.

Baseline preoperative, intraoperative and postoperative data and functional results are expressed as percentages and mean ± standard deviation. Qualitative and Quantitative statistical analysis were performed using paired sample test, independent sample test, pearson correlation, analysis of one way variance (ANOVA) and t' test. P value <0.05 was considered as the significant level. ROC curves were done to measure the cutoff value for TAPSE. Statistics performed using SPSS VERSION 16.0 (SPSS IncChicago)

Results

Of the 60 patients, 8 patients were excluded from the study, 2 patient's inability to introduce transesophageal (TEE) probe, 5 patients images could not be obtained post operative due to poor window, and 1 patient done on pump. A total of 52 patients were included in the study. Participants included 52 patients (43 males and 9 females) with a mean age of 58.2±12 years (ranged from 45 to 75 years). The mean BSA was 1.67 m^2.

Hemodynamic and Echocardiographic Data

The base line central venous pressure (CVP) varies from 7 to 17 mm of Hg with a mean of 12.10±2.546 mm Hg. Likewise the pulmonary capillary wedge pressure (PCWP) mean is around 13.00±3.10 mm of Hg. The EF varied from 36% -67% with a mean of 54.38±6.616 %. The mean post operative EF was 59.54% which ranged from 42%-65%.

TAPSE Value

The mean base line TAPSE value measured by TEE is 2.143 ± 0.4283cm which ranged from 1.4 -3.4cms. The values were increasing to a mean TAPSE of 2.423±0.3846 cms in the third postoperative period. The mean TAPSE value shows significant difference observed from base line to third postoperative day. Figure 1 (TAPSE ROC curve) represents the receiver operating characteristic curve demonstrating the ability of TAPSE to predict the post operative out come. The arrow indicates the optimal discriminatory cut of point corresponding to TAPSE of 1.78.

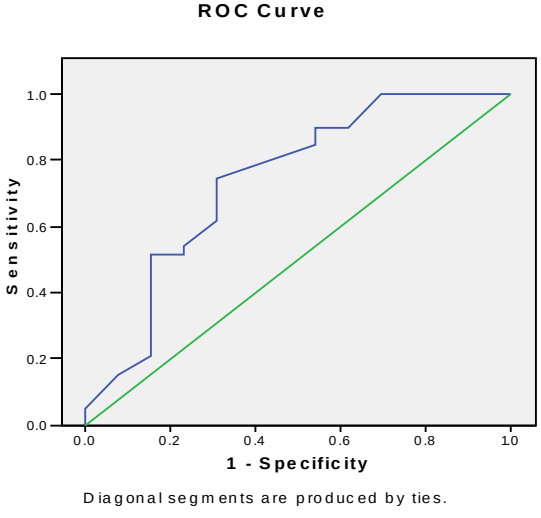

Fig. 1: TAPSE to predict the post operative out come

TAPSE and filling Pressures

Based on baseline TAPSE value, all patients were categorised into group A(<1.78) and group B (>1.78). group A have 12 and group B have 40 number of patients. Table 1 shows the mean central venous

pressure and pulmonary arterial pressures taken at the time of measuring TAPSE. In group A, the mean CVP and PCWP values are 13.92±2.021 and 15.58±3.175 respectively as compared to group B mean CVP and PCWP values are 11.55±2.449 and 12.23±2.655 respectively. There has been a significant raised filling pressures in group A compared to group B which is statistically significant. Post operatively in group A the mean CVP and PCWP values are 11.08±1.881 and 11.17±2.480 respectively as compared to group B mean CVP and PCWP values are 9.95±2.331 and 10.03±2.178 respectively. There was a decrease in filling pressures in both the groups in post operative period compared to preoperative period. The preoperative LVEF was lower in group A (49.50±8.24) as compared to group B (55.85±5.342). Whereas, post operative LVEF was lower in group A (53.25±5.27) as compared to group B (58.17±4.25). But both the groups showed an increase in the LVEF.

Table 1: Central venous pressure and pulmonary arterial pressures taken at the time of measuring TAPSE

		N	MEAN±SD	P value 2 Tailed
CVP PRE OP	GROUP A	12	13.92±2.021	0.004
	GROUP B	40	11.55±2.449	0.003
CVP POST OP	GROUPA	12	11.08±1.881	0.131
	GROUP B	40	9.95±2.331	0.098
PCWP PRE OP	GROUP A	12	15.58±3.175	0.001
	GROUP B	40	12.23±2.655	0.004
PCWP POST OP	GROUP A	12	11.17±2.480	0.129
	GROUP B	40	10.03±2.178	0.169

TAPSE and Perioperative out Come

50% of group A (6/12) while only 12.5% in group B (5/40) required inotropic support which is statistically significant. Thus there is a four fold increased usage of inotropes in patients with TAPSE <1.78cms. Only 17.3% of patients required ventilation more than 24 hours which is 50% in group A (6/12)compared to group B(3/40)7.5% which is statistically significant. That is there is a 6.6 folds increased duration of ventilation in patients with TAPSE value < 1.78cms. Only 13.5% of patients required ICU stay of >3 days which is 33.3% in group A (4/12) compared to group B (3/40)7.5% which is statistically significant. That is there is a 4.4 folds increased duration of ICU stay of more than 3 days in patients with TAPSE value < 1.78cms.

Adverse Events and Tapse

In group A, one patient had atrial fibrillation one had ventricular ectopics and one had stroke, whereas in group B one had atrial fibrillation one had ventricular ectopics. Neither of the two groups had new onset ST-T changes. Adverse events were not statistically significant in between both the groups.

PDA, RCA Grafting and Tapse

Table 2 shows that the PDA was grafted in 69% of patients (36/52) and RCA grafted in 7.6 %(4/52) of patients. There is a significant improvement of TAPSE values in patients with PDA grafting (mean 0.3117 cms) or RCA grafting (mean 0.1254 cms). However it did not show any statistical significance compared to those who did not receive PDA graft.

Table 2: PDA, RCA grafting and TAPSE

Grafting	No of Patients	Change In The Tapse Mean (cms)	SD	Paired Sample Test P Value
PDA	36	0.3117	0.2695	<0.01
NO PDA	16	0.2382	0.2886	<0.01
RCA	4	0.2600	0.1254	<0.01
NO RCA	48	0.2823	0.0415	<0.01

TAPSE and Stenosis on Coronary Angiogram

Table 3 represents the number of patients in each group with significant stenosis of one or more vessels on coronary angiogram. As compared to group B, Right coronary artery and more than one vessel significant narrowing on angiogram are significantly higher in group A which is statistically significant

Table 3: TAPSE and Significant Stenosis on CORONARY ANGIOGRAM

	Coronary artery narrowing	Group A	Group B	Significance p value <0.05
1	Left main	1(8.3%)	5(12%)	0.6988
2	LAD	7(58%)	25(62%)	0.7995
3	LCx	4(33%)	9(22.5%)	0.4570
4	RCA	6(50%)	13(32%)	0.2785
5	More than one vessel	6(50%)	10(25%)	0.1037

Table 4: RV Infarct area and TAPSE

	RV infarct area	Group A	Group B	Significance P value <0.05
1	None	3(25%)	29(72%)	0.0024
2	Free	4(30%)	6(15%)	0.1638
3	Posterior	5(41%)	5(12%)	0.0244
4	Apex	4 (30 %)	2(4.7%)	0.0064
5	More than one area	4(30%)	0(0)	<0.0001

Table 5: Area of myocardial infarct in left ventricle

	Area of LV infarct	Group A	Group B	Significance p value <0.05
1	Lateral	2(16%)	4(10%)	0.5354
2	Inferior	1(8.3%)	3(7.5%)	0.9261
3	Posterior	2(16%)	4(10%)	0.5354
4	Anterior	5(41.3%)	7(17.5 %)	0.0843
5	Septum	2(16%)	3(7.5%)	0.3546
6	Apex	3(25%)	2(4.7%)	0.0400
7	None	3 (25%)	27(64%)	0.0083
8	More than one	3(25%)	6(14%)	0.4319

The Table 4 represents area of myocardial infarct in right ventricle in each group. The involvement of right ventricle is more in group A as compared to group B as much as 3 fold It also shows that involvement of posterior area and more than one area involvement are significantly higher in group A compared to group B.

LV Infarct Area and TAPSE

The following Table 5 represents area of myocardial infarct in left ventricle in each group. The involvement of left ventricle is more in group A as compared to group B as much as 3 fold It also shows that involvement of posterior area and more than one area involvement are significantly higher in group A compared to group B.

Tricuspid Regurgitation

It was found that in group A three(25%) patients have moderate or severe regurgitation and in group B four patients (11%) have either moderate or severe there is 14% increase in the number of patients having tricuspid regurgitation.

Discussion

In the first half of 20th century, the study of RV function was limited to a small group of investigators who were intrigued by the hypothesis that human circulation could function adequately without RV contractile function [11].

Right Ventricular Systolic Function and Myocardial Infarction

Right ventricle is less susceptible to infarction than the left ventricle. In 1982, Goldstein and Colleagues showed that right ventricular myocardial infarction (RVMI) in a closed – chest dog model led to significant hemodynamic compromise [12].

Interestingly, right ventricular infarction noted at necropsy usually involves the posterior septum and posterior wall rather than the right free wall. The relative sparing of the right ventricular anterior wall apparently arises from a high degree of collateralization.

In our study group A patients (TAPSE <1.78) increased percentage of infracts in the posterior wall,

freewall and apical segment of right ventricle and anterior wall of left ventricle compared to group B.

There is also significant percentage of right coronary artery involvement in group A patients compared to group B. Studies have demonstrated that more proximal right coronary artery occlusions result in larger right ventricular infarctions. On occasion, the right ventricle can be subjected to infarction from occlusion of the left circumflex coronary artery [13].

Right Ventricular Systolic Functions and Filling Pressures

In our study, patients with TAPSE values less than 1.78 were found to have higher filling pressures CVP and PCWP than those with tapse values >1.78. The finding of an inverse relation between RV systolic function and PAP is in accordance with most previous pathophysiologic studies. Interestingly, this relation was similar between patients with dilated cardiomyopathy and those with ischemic heart disease, supporting the concept that in patients with heart failure due to primary dilated cardiomyopathy or to ischemic heart disease, the major determinant of the impairment in systolic function of the RV is afterload mismatch.

Stefano Ghio et al in his study showed that exception to this rule can may be observed in clinical practice. First in some patients with recently origin pulmonary hypertension the right ventricular function can be fairly preserved. Second the right ventricle dysfunction may be present with normal pulmonary artery pressures [14].

Right Ventricular Systolic Function and TAPSE

Assessment of RV has been challenging for the reasons like the complex geometry of the Right ventricle, poor definition of endocardial surface , the retrosternal position of RV and marked load dependence of indices of RV function.

In our study post operative trans thoracic echocardiographic images could not be obtained in five patients on ventilator on first post operative day.

Tricuspid Annular plane systolic excursion is another useful quantitative measurement of RV systolic performance. Studies showed that there is a good correlation between tricuspid annular plane systolic excursion and RVEF measured by radionuclide angiography [15] and MRI [16].

Because of its relative ease of acquisition, low inter- and intraobserver variability and the objective nature of data obtained. A long track record as a large number of studies simpleness, reproducibility, lack of inter observer variability we selected TAPSE as a method of assessment of RV Systolic function in our study.

In our study, we have found that there is statistically significant improvement of RV systolic function following off pump CABG surgery as shown by increasing TAPSE values in post operative period. There was improvement of TAPSE in both the groups when compared to the base line.

Right Ventricular Systolic Function and PDA Or RCA Grafting

Schrmer u et al compared right ventricular function in patients with and without PDA grafting on cardiopulmonary bypass pump in 20 patients and concluded that right ventricular depression can occur after bypass grafting in patients with a moderate stenosis that is not revascularized. While revascularization of more severe stenosis of right coronary artery(RCA) appears right to preserve post operative right ventricular function [17].

In our study, out of 52 patients, almost 76% of the patients had either PDA (36 patients) or distal RCA (4 patients) and there was a significant increase in the right ventricular function in these patients. Interestingly irrespective of whether right coronary is being grafted or not there is statistically significant improvement in RV systolic function post grafting. This finding can be partly explained by improvement of RV systolic function by "Ventricular interdependence" mechanism [18].

Right Ventricular Systolic Function and Left Ventricular Ejection Fraction (LVEF)

In our study, the left ventricular EF in group A was found to be less than group B in the postoperative period both the groups have increase ejection fraction.

Left ventricular function significantly affects right ventricular systolic function a phenomenon called systolic interventricular dependence [18]. Experimental studies have shown that about 20% to 40% of the right ventricular systolic pressure and volume outflow result from left ventricular contraction. This dependency of the right ventricle on the left ventricle helps to explain the right ventricular response to volume overload, pressure overload, and myocardial ischemia. Ventricular interdependence causes overall ventricular

deformation, and is probably best explained by the balance of forces at the interventricular sulcus, the material properties, and cardiac dimensions [18].

Right Ventricular Systolic Function and Patient out Come

Ghios et al in his study in chronic CHF patients with left ventricular ejection fraction <35% found that TAPSE < or =14 mm added significant (p <0.03) prognostic information to NYHA class III or IV, left ventricular ejection fraction of <20%, and mitral deceleration time of < 125 ms(19). Although not included in the current guidelines, the assessment of RV function provides complementary information that can further refine risk stratification in patients with heart failure due to LV dysfunction of ischemic or non-ischemic etiology. Several prospective studies have investigated the use of TAPSE to this end. A value for TAPSE < 1.4 cm has been shown to be an independent predictor of all cause mortality in several cohorts of patients with systolic LV failure [20].

In one study by scuteri etal in his follow up of patients who under went Cardiac resynchronization therapy for a period of six months, a TAPSE of less than 1.4 cm was strongly associated with failure of CRT to improve clinical status and LV remodeling [21].

TAPSE has recently emerged as an important predictor of prognosis. In a large cohort of patients with pulmonary hypertension (the majority being in the WHO class 1 of pulmonary hypertension), a TAPSE of < 1.8 cm was strongly associated with a lower cardiac index as well as a much higher mortality rate over a median follow-up of 19 months [22].

In the present study TAPSE values less than 1.78 cm in the preoperative period is associated with significant increase in the duration of ventilation, inotropic support and ICU stay. There are also more incidences of rhythm abnormalities and stroke.

Conclusion

Right ventricular systolic function can be assessed with ease in perioperative setting. Right ventricular systolic function improves significantly after off pump CABG surgeries. This has been clearly shown by increase in Tricuspid annular plane systolic excursion (TAPSE). Patients with decreased systolic function have TAPSE values of less than 1.76.

References

1. Dávila-Román VG, Waggoner AD, Hopkins WE, Barzilai B. Right ventricular dysfunction in low output syndrome after cardiac operations: assessment by transesophageal echocardiography. Ann Thorac Surg. 1995; 60(4):1081-6.
2. Hedman A, Alam M, Zuber E, Nordlander R, Samad BA. Decreased right ventricular function after coronary artery bypass grafting and its relation to exercise capacity: a tricuspid annular motion-based study. J Am Soc Echocardiogr. 2004; 17(2):126-31.
3. Michaux I, Filipovic M, Skarvan K, Schneiter S, Schumann R, Zerkowski HR, Bernet F, Seeberger MD. Effects of on-pump versus off-pump coronary artery bypass graft surgery on right ventricular function. J Thorac Cardiovasc Surg. 2006; 131(6): 1281-8.
4. Reichert CL, Visser CA, van den Brink RB, Koolen JJ, van Wezel HB, Moulijn AC, Dunning AJ. Prognostic value of biventricular function in hypotensive patients after cardiac surgery as assessed by transesophageal echocardiography. J Cardiothorac Vasc Anesth. 1992; 6(4):429-32.
5. Rose EA. Off-pump coronary-artery bypass surgery. N Engl J Med. 2003; 348(5):379-80.
6. Roshanali F, Yousefnia MA, Mandegar MH, Rayatzadeh H, Alinejad S. Decreased right ventricular function after coronary artery bypass grafting. Tex Heart Inst J. 2008; 35(3):250-5.
7. Cheng DC, Bainbridge D, Martin JE, Novick RJ, Evidence-Based Perioperative Clinical Outcomes Research Group. Does off-pump coronary artery bypass reduce mortality, morbidity, and resource utilization when compared with conventional coronary artery bypass? A meta-analysis of randomized trials. Anesthesiology. 2005; 102(1): 188-203.
8. Puskas J, Cheng D, Knight J, Angelini G, DeCannier D, Diegeler A, Dullum M, Martin J, Ochi M, Patel N, Sim E. Off-pump versus conventional coronary artery bypass grafting: a meta-analysis and consensus statement from the 2004 ISMICS consensus conference. Innovations: Technology and techniques in cardiothoracic and vascular surgery. 2005; 1(1):3-27.
9. Reichert CL, Visser CA, van den Brink RB, Koolen JJ, van Wezel HB, Moulijn AC, Dunning AJ. Prognostic value of biventricular function in hypotensive patients after cardiac surgery as assessed by transesophageal echocardiography. J Cardiothorac Vasc Anesth. 1992; 6:429–432.
10. Hensley, Frederick A., Donald Eugene Martin, and Glenn P. Gravlee, eds. A practical approach to cardiac anesthesia. Lippincott Williams & Wilkins, 2012.

11. Goor, Daniel A., and C. Walton Lillehei. Congenital malformations of the heart: embryology, anatomy, and operative considerations. Grune & Stratton, 1975.
12. Goldstein J. The right ventricle: what's right and what's wrong. Coron Artery Dis. 2005; 16:1-3.
13. Kaul S, Tei C, Hopkins JM, Shah PM. Assessment of right ventricular function using two-dimensional echocardiography. Am Heart J 1984; 107:526-31.
14. Ghio S, Gavazzi A, Campana C, Inserra C, Klersy C, Sebastiani R, Arbustini E, Recusani F, Tavazzi L. Independent and additive prognostic value of right ventricular systolic function and pulmonary artery pressure in patients with chronic heart failure. Journal of the American College of Cardiology. 2001; 37(1):183-8.
15. Ueti OM, Camargo EE, de A Ueti A, de Lima-Filho EC, Nogueira EA. Assessment of right ventricular function with Doppler echocardiographic indices derived from tricuspid annular motion: comparison with radionuclide angiography. Heart. 2002; 88(3): 244-8.
16. Kjaergaard J, Petersen CL, Kjaer A, Schaadt BK, Oh JK, Hassager C. Evaluation of right ventricular volume and function by 2D and 3D echocardiography compared to MRI. Eur J Echocardiogr 2006; 7:430-8.
17. Maslow AD, Regan MM, Panzica P, Heindel S, Mashikian J, Comunale ME. Precardiopulmonary bypass right ventricular function is associated with poor outcome after coronary artery bypass grafting in patients with severe left ventricular systolic dysfunction. Anesthesia & Analgesia. 2002; 95 (6):1507-18.
18. Santamore WP, Dell'Italia. LJVentricular interdependence: significant left ventricular contributions to right ventricular systolic function. Prog Cardiovasc Dis. 1998; 40(4):289-308.
19. Ghio S, Recusani F, Klersy C, Sebastiani R, Laudisa ML, Campana C, Gavazzi A, Tavazzi L. Prognostic usefulness of the tricuspid annular plane systolic excursion in patients with congestive heart failure secondary to idiopathic or ischemic dilated cardiomyopathy. The American journal of cardiology. 2000 Apr 1; 85(7):837-42.
20. Zeineh N, Champion H. Utility of tricuspid annular plane systolic excursion in the assessment of right ventricular function. PVRI Review. 2010; 2(1):17.
21. Scuteri L, Rordorf R, Marsan NA, Landolina M, Magrini G, Klersy C, et al. Relevance of echocardiographic evaluation of right ventricular function in patients undergoing cardiac resynchronization therapy. Pacing Clin Electrophysiol 2009; 32:1040-9.
22. Raymond RJ, Hinderliter AL, Willis PW, Ralph D, Caldwell EJ, Williams W, et al. Echocardiographic predictors of adverse outcomes in primary pulmonary hypertension. J Am Coll Cardiol 2002; 39:1214-9.