Original Article

# 2D Speckel Tracking of RV Function after CABG and CPB Time

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## Abstract

**Aim:** To investigate the relation between the postoperative RV dysfunction and cardiopulmonary bypass time (CPB time) and aortic cross clamp time by comparing new echocardiographic parameter (2D speckel tracking). **Methods and Results:** We included 38 patients who underwent CABG between March 2019 and November 20019 in the Academic Medical Centre in Tehran. Before and one week after CABG, patients had TEE,71% were male. There was statistically significant decrease in RVGLS from (-19 to -11) after CABG. There w ere significant correlation between Pre op TAPES and FAC (*P* value=0.002), pre op FAC and Sv (*P* value=0.001), Pre op TAPES and GLS (*P* value=0.011) and Pre op Sv and GLS (*P* value=0.013) And there was significant correlation between post op TAPES and FAC (*P* value=0.045) and Post op Sv and GLS (*P* value=0.04), **Conclusion:** There is not significant correlation between decline in RV function parameter (TAPES, GLS, FAC, Sv) and cardiopulmonary bypass time and aortic cross clamp time.

**Keywords:** Cardiopulmonary bypass time, coronary artery bypass grafting, speckle tracking

## Introduction

A decrease in right ventricular (RV) function is an event known to occur after coronary artery bypass grafting (CABG). Intraoperative or postprocedure RV dysfunction is linked with high postoperative mortality.[1,2]

RV dysfunction can be seen during and immediately after cardiac surgery. Although the mechanism of this phenomenon is not well understood, cardiopulmonary bypass time (CPB), perioperative myocardial ischemia, intraoperative myocardial damage, cardioplegia, and pericardial disruption or adhesion have been suggested as the probable causes.

RV assessment can be challenging due to its anterior location and complex crescent‑shaped geometry, which poses particular imaging difficulties in the intraoperative setting. Prior studies have shown that commonly used indices of RV function such as tricuspid annular plane systolic excursion (TAPSE) can be altered by pericardiotomy itself.[3,4] For example, decrements in longitudinal shortening have been shown to result in gains in transverse shortening,[5] thereby further limiting the traditionally used longitudinal measures of RV performance, TAPSE and right ventricular systolic excrusion velocity (RV S′).

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Myocardial deformation via two‑dimensional speckle tracking echocardiography (2D STE) provides incremental value in prognostic stratification as compared to the traditional indices for RV function evaluation.[6-8] 2D STE has shown to have a significant correlation with RV ejection fraction by cardiac magnetic resonance.[9] STE imaging provides frame‑by‑frame tracking of natural acoustic marker. In particular, the angle‑independent nature of speckle tracking has the potential to overcome the limitations of 2D linear indices of TAPSE and S′ and is not influenced by translational movement due to respiration or tethering by the adjacent myocardium and less sensitive to signal noise. Several studies have revealed that RV longitudinal systolic strain measurements by STE may be a valuable method for assessing the RV function because it can provide prognostic data and is more reliable than conventional parameters.[10-15] 2D STE is currently the method of choice. The goal of this study was to determine the effect of aortic cross‑clamp time and pump time on RV function by using both standard 2D and speckle tracking methods.

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## Patients and Methods

We recruited patients who had been referred to our hospital's echo lab from March 2019 to November 2019 for elective CABG. Of the total patients, one patient died 4 days after CABG because of massive pulmonary thromboembolism and four were lost to follow-up; the study population (38 patients), therefore, comprised 27 men and 11 women. The mean age was 58.3 years (range, 42–81 years); 36.7% of the patients were ≥65 years old. Twenty (52%) patients had diabetes mellitus, 22 patients (57.8%) were hypertensive, four patients (10%) had CRF, five patients (13%) had COPD, and 4 patients (10%) were in atrial fibrillation rhythm. Nobody had history of CABG [Table 1].

### Surgical technique

Standard hypothermic (approximately 32°C) cardiopulmonary bypass was used in all patients. Blood cardioplegic solution, delivered via both antegrade and retrograde routes, was used to ensure myocardial protection. All patients in the study underwent total revascularization. In additional to CABG, five patients underwent valve surgery (one patient had aortic valve replacement, two patients had mitral valve repair [MVR], and two patients had MVR), none of the patients had severe tricuspid regurgitation and severe pulmonary hypertension, and there was no need for tricuspid valve (TV) ring annuloplasty or TV replacement [Table 2].

### Study design

Transthoracic echocardiography (baseline 2D echocardiography, tissue doppler imaging, and speckel tracking of RV) were performed prior to CABG and 1 week after CABG by using commercial equipment (SIEMENCE echo machine (ACUSON S 2000)) [Table 3].

2D TTE RV systolic function was quantified using TAPSE, RV-S′, and fractional area of change (FAC), which were acquired in accordance with consensus guidelines. TAPSE was measured on M-mode as the systolic excursion of the lateral tricuspid annulus along its longitudinal plane and RV-S′ on tissue Doppler as the peak tricuspid annular velocity of excursion. FAC was measured through planimetry of end-diastolic and end-systolic contours in four-chamber orientation. The established FAC cutoff (<35%) was used to identify RV dysfunction.

Speckle-tracking strain images were analyzed offline for deformation analysis. Strain measurements were performed by an investigator experienced in the interpretation of echocardiographic images, blinded to the results of the 2D measurements. Each image was acquired in RV-focused view with a frame rate >50 Hz for analysis of RV strain. The RV end-diastolic endocardial border was manually traced and the software automatically generated a second line at the level of epicardium, delineating a region of interest frame by frame throughout the cardiac cycle. Epicardial contour was manually adjusted when necessary to optimize tracking. The established global longitudinal strain (GLS) cutoff (−20%) was used to identify RV dysfunction according to the European Association of Cardiovascular Imaging/American Society of Echocardiography inter-vender comparison study (J AM Soc Echocardiography, 2015).

**Table 1: Basic and demographic data of the participants**

| Basic data | Number |
|---|---|
| *n* | 38 |
| Age | 63.54 |
| Female (%) | 11 (28) |
| DM (%) | 20 (52) |
| HTN (%) | 22 (57) |
| CRF (%) | 4 (10) |
| COPD (%) | 4 (10) |
| AF (%) | 4 (10) |

COPD: Chronic obstructive pulmonary disease, HTN: Hypertension, CRF: Chronic renal failure, AF: Atrial fibrillation

**Table 2: Perioperative variables**

| Perioperative data | Result |
|---|---|
| CABG + MVR | 2 patients |
| CABG + MVR | 2 patients |
| CABG + AVR | 1 patient |
| CPB time | 120 min |
| Aortic cross-clamp time | 68.2 min |

CABG: Coronary artery bypass grafting, CPB: Cardiopulmonary bypass time, MVR: Mitral valve repair, AVR: Aortic valve replacement

**Table 3: Preoperative and postoperative echocardiographic parameters**

| Echo parameter | Result |
|---|---|
| Preoperative RV enlargement* | 2 (5%) |
| Postoperative RV enlargement | 3 (7%) |
| Preoperative RV dysfunction$^+$ | 7 (18%) |
| Postoperative RV dysfunction | 34 (89%) |
| Preoperative PHTN$^\#$ | 8 (21%) |
| Postoperative PHTN | 6 (15%) |
| Preoperative PAP | 32 mmHg |
| Postoperative PAP | 29.2 mmHg |
| Preoperative LVEF (%) | 48 (%) |
| Postoperative LVEF (%) | 41.5 (%) |
| Preoperative TAPES | 20 mm |
| Preoperative TAPES | 13.73 mm |
| Preoperative SV | 10 m/s |
| Postoperative SV | 7 m/s |
| Preoperative GLS | −19 |
| Postoperative GLS | −11 |
| Preoperative FAC | 36.5 (%) |
| Postoperative FAC | 27 (%) |

*RVEDD >34 mm in base of RV in RV focused view, $^+$FAC<35% and SV <9.5 cm/s, $^\#$Systolic PAP >35 mmHg, based on TR velocity (4 TR velocity 2 + RAP). RV: Right ventricular, RVEDD: RV end-diastolic diameter, PAP: Positive airway pressure, FAC: Fractional area of change, TR: Tricuspid regurgitation, PHTN: Pulmonary hypertension, LVEF: Left ventricular ejection fraction, GLS: Global longitudinal strain, SV: Stroke volume

### Statistics

For statistical analysis, SPSS software version 19 was used. Data were expressed as median and interquartile range or number (percentage).

Because the number of participants in the study was small, and many of the variable did not fit normal distributions, nonparametric test was used to compare the data.

Spearman`s coefficient was used to assess the correlation between RV function changes and cardiopulmonary bypass time and aortic cross-clamp time.

The Wilcoxon matched-pair single-rank test helped in the comparison of pre- and post-CABG values for GLS, TAPES, stroke volume (SV), and FAC.

## Results

A total of 38 cases under CABG procedure were enrolled with a mean (standard deviation) age of 63.21 years (8.82) ranging from 44 to 81 years. None of the patients needed pacemaker and one patient, pre-CABG, had an implantable cardioverter defibrillator.

Among them, 27 cases (71.1%) were male patients. In this study, one patient had inferior + RV myocardial infarction, nobody had ischemic events after CABG, two patients were left circumflex artery dominant, and one patient had right coronary artery (RCA) anomaly, that originated from the left coronary system.

100% of the studied patients had left internal mammary artery (LIMA) graft to the left anterior descending (LAD) artery; 77% had LIMA graft to LAD artery, saphenous vein graft (SVG) to the obtuse marginal (OM) artery, and SVG to the RCA; 18% had both LIMA graft to the LAD artery and SVG to the OM artery; and 5% had both LIMA to LAD and SVG to RCA. The mean of CPB time was 120 min, and the mean of aortic cross-clamp time was 68.2 min. RV free wall dysfunction was seen in 88% of patients. As demonstrated in Table 4, on Wilcoxon test, there was a statistically significant difference between TAPSE, FAC, SV, and GLS before and after CABG procedure that is shown as median (interquartile range).

By STE, there was a statistically significant decrease in RVGLS from −19 to −11 after CABG. There was a statistically significant decrease in right ventricle free wall longitudinal strain (apical decrease from −23.73 to −13.7, mid-cavity decrease from −25.76 to −11.53, basal decrease from −20.39 to −10.13, and lateral wall declined from −23.01 to −9.13). There was a statistically significant decrease in interventricular septum longitudinal strain (apical decrease from −19.77 to −10.06, mid-cavity decrease from −17.81 to −10.87, and basal decrease from −15.89 to 11.13).

There was a significant correlation between preoperative TAPES and FAC ($P$ = 0.002), preoperative FAC and SV ($P$ = 0.001), preoperative TAPES and GLS ($P$ = 0.011), and preoperative SV and GLS ($P$ = 0.013).

**Table 4: Preoperative and postoperative variables**

| Factors | Before CABG | After CABG | *P* |
|---|---|---|---|
| GLS | −19.0 (−21.0- −11.0) | −11.0 (−15.0- −9.0) | 0.002 |
| FAC | 36.5 (31.0- 41.0) | 27.0 (20.0- 30.0) | <0.001 |
| SV | 10.0 (10.0- 10.25) | 7.0 (6.0- 8.0) | <0.001 |
| TAPSE | 20.0 (18.0- 21.0) | 13.0 (12.0- 16.0) | <0.001 |

GLS: Global longitudinal strain, FAC: Fractional area of change, TAPSE: Tricuspid annular plane systolic excursion, CABG: Coronary artery bypass grafting, SV: Stroke volume

**Table 5: Correlation between pump time and aorta cross-clamp time with different tricuspid annular plane systolic excursion, fractional area of change, Sv, and global longitudinal strain measures pre- and post-coronary artery bypass grafting**

| Factors | Pump_time | Aortic_cross-clamp_time |
|---|---|---|
| Diff_GLS | | |
| Correlation coefficient | 0.013 | −0.003 |
| Significant (two tailed) | 0.939 | 0.985 |
| Diff_FAC | | |
| Correlation coefficient | 0.146 | 0.001 |
| Significant (two tailed) | 0.381 | 0.997 |
| Diff-SV | | |
| Correlation coefficient | 0.253 | 0.183 |
| Significant (two tailed) | 0.125 | 0.271 |
| Diff-TAPES | | |
| Correlation coefficient | 0.061 | 0.113 |
| Significant (two tailed) | 0.717 | 0.499 |

GLS: Global longitudinal strain, FAC: Fractional area of change, TAPSE: Tricuspid annular plane systolic excursion, SV, RV systolic excrusion velocity

Moreover, there was a significant correlation between postoperative TAPES and FAC ($P$ = 0.045) and postoperative SV and GLS ($P$ = 0.04).

There was no significant correlation between decline in RV function parameter (TAPES, GLS, FAC, and SV) and CPB and aortic cross-clamp time [Table 5].

## Discussion

RV dysfunction is recognized as an important factor of mortality and morbidity, and its importance as a prognostic index after surgery has been widely demonstrated.[11] Accurate postoperative assessment of RV function is crucial and should be based on reliable and reproducible measurements.

In practice, right ventricle echocardiographic evaluation has been limited in the past due to the complex structure and anatomy of the right ventricle, so myocardial deformation via 2D STE provides incremental value in prognostic stratification as compared to traditional indices for RV function evaluation. Despite the wide relevance of RV strain in the study of various RV disorders, this technique has been used infrequently in the evaluation of post-CABG RV dysfunction.

Several hypotheses have been proposed to explain loss in RV performance, including (1) cardiopulmonary bypass use.[16,17] In a state of cardiopulmonary bypass, the body releases cytokines which initiate inflammation and pulmonary vasoconstriction. One of these cytokines is endothelin-1.[18,19] Endothelin-1 has a vasoconstrictive effect on the pulmonary arterioles and might consequently influence RV afterload.[20] Endothelin-1 appears to play a modest role in healthy organisms, but probably plays a major role in many pathophysiological states.[21] Bond *et al*. demonstrated that patients with elevated postoperative endothelin-1 levels stayed longer on the intensive care unit (ICU) and had longer overall hospitalization;[15] (2) geometrical changes of the RV chamber (in association with interventricular septal paradoxical motion[22]); (3) intraoperative ischemia; (4) right atrial injury due to cannulation procedure;[23] (5) poor myocardial protection;[24] and (6) extramyocardial causes (pericardial disruption, changes in fossa oval, and postoperative adherence of the right ventricle to the thoracic wall[25]).

The primary aim of this study was to determine and predict the change in RV function after CABG and correlation of it with CPB time and aortic cross-clamp time; baseline RV dysfunction was observed in 18% of the patients and postoperative function of RV reduces significantly in more than 90% of patients, ($P = 0.01$) and is associated with significant alterations in RV GLS and conventional 2D RV parameter in comparison before and after CABG.

RV function reduces after cardiac surgery, and it is reported by most of investigators.[11] In our study (baseline vs. post-CPB), TAPES decreased from 20 to 13.73 mm, SV decreased from 10 to 7.11 cm/s, FAC decreased from 36.5% to 27%, and 2D STE GLS increased from −19 to −11.95.

In this study, the mean GLS in the preoperative period was −19, which was lower than normal, but the mean of other parameters (TAPES, FAC, and SV) was normal; this would have revealed GLS drop earlier and can predict subclinical RV dysfunction.

There was a significant correlation between preoperative TAPES and FAC ($P = 0.002$), preoperative FAC and SV ($P = 0.001$), preoperative TAPES and GLS ($P = 0.011$), and preoperative SV and GLS ($P = 0.013$).

Moreover, there was a significant correlation between postoperative TAPES and FAC ($P = 0.045$) and postoperative SV and GLS ($P = 0.04$).

However, there was no significant correlation between decline in RV function parameters (TAPES, GLS, FAC, and SV) and CPB and aortic cross-clamp time.

Because post-CABG RV dysfunction is accompanied with poor prognosis, this subject demonstrates the further importance of GLS versus other three markers to determine RV function. If this study was done with prognostic preferences, the authors would have able to calculate and measure the sensitivity and specificity beside positive and negative predictive values and it could have helped to elucidate the help true prognostic values of these markers, especially for GLS index.

A similar study by Rong *et al*.[26] in the USA in 2019 among 53 patients revealed that abnormal RV strain is correlated with RV functional decline after CABG and offers important predictive role in predicting RV dysfunction in postoperative phase. Conversely, a study by Grønlykke *et al*.[27] showed that TAPSE had significant decrease after CABG, but SV and GLS were relatively stable and generally 3D echocardiography had regular underestimation of approximately 10%.

The cohort by Gozdzik *et al*.[28] in Poland demonstrated among 69 cases that GLS was a good predictive factor for early outcome in post-CABG phase that is in line with our results. Similarly, Howard-Quijano *et al*.[29] reported with a assessment of 163 cases that preoperative strain in 3D assessment is an independent predictor of clinical outcomes after cardiac surgeries including both acute and long-term periods. However, the long-term outcomes may be studied in the same population to attain more reliable results in our population. A review study by Abuelkasem *et al*.[30] declaimed that STE is an imaging modality that can recognize the small segments of the myocardium and develop further details for assessing global and regional RV dysfunction, as seen in our study.

A French study by Ternacle *et al*.[31] assessed 425 patients under cardiac surgery and revealed that as a prognostic index, the GLS may predict post-CABG mortality. However, in our study, similar findings were not seen due to smaller sample population and shorter follow-up interval. Interestingly, Modin *et al*.[32] declaimed that corrected GLS (by RR interval) but not uncorrected GLS is significantly associated with higher risk of all-cause mortality in cardiac patients.

Prolonged cumulative CPB time (>180 min) was significant in predicting mortality while adjusting for EuroSCORE II, postoperative complications, prolonged ICU stay, and prolonged mechanical ventilation.[33]

Prolonged cross-clamping time and CPBT are associated with mortality and development of severe complications after valvular surgery for infective endocarditis.[34]

Among patients undergoing elective CABG operations, there is a direct and linear correlation between aortic cross-clamp time and postoperative troponin I levels. We strongly advocate this 50 min threshold as a safety limit for aortic cross-clamp time in elective CABG surgery.[35]

Acute intraoperative reduction in RV function occurs following CPB, independent of procedural characteristics and pericardiotomy.[36]

Regional and global RV function, as demonstrated by 2D markers and strain, acutely decline intraoperatively. Moreover, 2D STE of the RV at baseline predicts intraoperative RV dysfunction, whereas conventional techniques do not. These findings add to the growing body of literature demonstrating that RV function is significantly impaired during cardiac surgery and suggests that deformational imaging provides incremental value in predicting those who will develop RV dysfunction. The ability to predict this dysfunction could help identify those patients in whom further intraoperative supports are needed. The current study had some limitations.

This was the first study to report and assess RV function by RV speckle tracking and compare it with conventional methods in patients who underwent CABG before and after CABG and evaluate its relationship with CPB.

### Limitations

Our study had several limitations. First the strain algorithms used in this study were validated for LV strain and were not designed for assessing RV strain, while the strain algorithms were not chamber specific.

Second, it was a single-center study and the number of patients was small; thus, a multicentric study with high-volume cases needs to be carried out.

Third, assessment of 2D speckle tracking is currently available only in the apical four-chamber view, whereas the assessment of LV strain is obtained by the three classic views.

Fourth, strain values differ among different software vendors.

## Conclusions

Global and regional RV functions, as measured by 2D indices and strain, acutely decline after CABG. The ability to predict this dysfunction could help identify those patients in whom support is needed. This subject demonstrates the further importance of GLS (better parameter) versus other three markers to determine RV function and sub-clinical RV dysfunction. In our study, we did not find a significant correlation between time of CPB and change in RV function.

### Ethical clearance

The ethical approval of the present study was taken from the health ethics committee of our Board for Medical Specialties. The confidentiality of personal information was protected throughout the study steps.

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### Conflicts of interest

There are no conflicts of interest.

## References

1. Bootsma IT, de Lange F, Koopmans M, Haenen J, Boonstra PW, Symersky T, *et al*. Right ventricular function after cardiac surgery is a strong independent predictor for long-term mortality. J Cardiothorac Vasc Anesth 2017;31:1656-62.
2. 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. Anesth Analg 2002; 95:1507-18.
3. Unsworth B, Casula RP, Kyriacou AA, Yadav H, Chukwuemeka A, Cherian A, *et al*. The right ventricular annular velocity reduction caused by coronary artery bypass graft surgery occurs at the moment of pericardial incision. Am Heart J 2010;159:314-22.
4. Okada DR, Rahmouni HW, Herrmann HC, Bavaria JE, Forfia PR, Han Y. Assessment of right ventricular function by transthoracic echocardiography following aortic valve replacement. Echocardiography 2014;31:552-7.
5. Raina A, Vaidya A, Gertz ZM, Susan C, Forfia PR. Marked changes in right ventricular contractile pattern after cardiothoracic surgery: implications for post-surgical assessment of right ventricular function. J Heart Lung Transplant 2013;32:777-83.
6. Motoki H, Borowski AG, Shrestha K, Hu B, Kusunose K, Troughton RW, Tang WH, Klein AL. Right ventricular global longitudinal strain provides prognostic value incremental to left ventricular ejection fraction in patients with heart failure. J Am Soc Echocardiogr 2014;27:726-32.
7. Kim J, Alakbarli J, Yum B, Tehrani NH, Pollie MP, Abouzeid C, Di Franco A, Ratcliffe MB, Poppas A, Levine RA, *et al*. Tissue-based markers of right ventricular dysfunction in ischemic mitral regurgitation assessed via stress cardiac magnetic resonance and three-dimensional echocardiography. Int J Cardiovasc Imaging 2019;35:683-93.
8. Motoji Y, Tanaka H, Fukuda Y, Ryo K, Emoto N, Kawai H, Hirata K. Efficacy of right ventricular free-wall longitudinal speckle-tracking strain for predicting long-term outcome in patients with pulmonary hypertension. Circ J 2013;77:756-63.
9. Hmilton-craig CR. Accuracy of quantitive echocardiography measurement of RV function as compared to CMR,IJC Heart &vasculature 2016:12:38-44.
10. Pirat B, McCulloch ML, Zoghbi WA. Evaluation of global and regional right ventricular systolic function in patients with pulmonary hypertension using a novel speckle tracking method. Am J Cardiol 2006;98:699-704.
11. Sachdev A, Villarraga HR, Frantz RP, McGoon MD, Hsiao J-F, Maalouf JF, *et al*. Right ventricular strain for prediction of survival in patients with pulmonary arterial hypertension. Chest 2011;139:1299-309
12. Kato TS, Jiang J, Schulze PC, Jorde U, Uriel N, Kitada S, *et al*. Serial echocardiography using tissue Doppler and speckle tracking imaging to monitor right ventricular failure before and after left ventricular assist device surgery. JACC Heart Failure 2013;1:216-22.
13. Yu H-k, S-j L, Ip JJ, Lam WW, Wong SJ, Y-f C. Right ventricular mechanics in adults after surgical repair of tetralogy of Fallot: insights from three dimensional speckle-tracking echocardiography. J Am Soc Echocardiography 2014;27:423-9.
14. Chang W-T, Tsai W-C, Liu Y-W, Lee C-H, Liu P-Y, Chen J-Y, *et al*. Changes in right ventricular free wall strain in patients with coronary artery disease involving the right coronary artery. J Am Soc Echocardiography 2014;27:230-8.
15. Li Y, Wang Y, Ye X, Kong L, Zhu W, Lu X. Clinical study of right ventricular longitudinal strain for assessing right ventricular dysfunction and hemodynamics in pulmonary hypertension. Medicine 2016;95(50).
16. Pegg TJ, Selvanayagam JB, Karamitsos TD, Arnold RJ, Francis JM, Neubauer S, *et al.* "Effects of off-pump versus on-pump coronary artery bypass grafting on early and late right ventricular function," Circulation, vol. 117, p. 2202-10, 2008.
17. Forsberg LM, Tam´as E, Anky FV, Nielsen NE, Engvall J, Nylander E. "Left and right ventricular function in aorticstenosispatients8weekspost-transcatheteraorticvalve implantation or surgical aortic valve replacement," European Journa lo f Echocardiography, vol.12, no.8, pp.603-11, 2011.
18. Roshanali F, Yousefnia M, Mandegar M, Rayatzadeh H, Alinejad S. "Decreased right ventricular function after coronary arterybypas. grafting," Texas Heart Institute Journal vol.35, pp.250-5, 2008.
19. Lindqvist P, Holmgren A, Zhao Y, Henein MY, "Effect of pericardia l repair after aortic valve replacement on septal and right ventricular function," International Journal of Cardiology, vol.155, pp.388-93, 2012.
20. Jasinski M, Ka¸ dzioła Z, Bachowski R, "Comparison of retrograde versus antegrade cold blood cardioplegia: Randomized trial in elective coronary artery bypass patients," European Journal of Cardio-thoracic

Surgery, 1997:12; pp. 620-26.
21. Joshi SB, Salah AK, Mendoza DD, Goldstein SA, Fuisz AR, Lindsay J. “Mechanism of paradoxical ventricular septal motion after coronary artery bypass grafting,” American Journal of Cardiology, 2009:103;212-5.
22. Bond BR, Dorman BH, Clair MJ, Walker CA, Pinosky ML, Reeves ST, *et al*. Endothelin-1 during and after cardiopulmonary bypass: association to graft sensitivity and postoperative recovery. J Thorac Cardiovasc Surg 2001;122:358–364.
23. Ford RL, Mains IM, Hilton EJ, Reeves ST, Stroud RE, Crawford FA Jr., *et al*. Endothelin-A receptor inhibition after cardiopulmonary bypass: Cytokines and receptor activation. Ann Thorac Surg 2008;86:1576-83.
24. ValerioJG, Coghlan JG. Bosentan in the treatment of pulmonary arterial hypertension with the focus on the mildly symptomatic patient. Vasc Health Risk Manag 2009;5:607-19.
25. McNeill JR. Role of endothelin in regulation of resistance, fluid-exchange, and capacitance functions of the systemic circulation. Can J Physiol Pharmacol 2003;81:522-32.
26. Rong LQ, Yum B, Abouzeid C, Palumbo MC, Brouwer LR, Devereux RB, *et al*. Echocardiographic predictors of intraoperative right ventricular dysfunction: A 2D and speckle tracking echocardiography study. Cardiovasc Ultrasound 2019;17:11.
27. Grønlykke L, Korshin A, Holmgaard F, Kjøller SM, Gustafsson F, Nilsson JC, *et al*. Severe loss of right ventricular longitudinal contraction occurs after cardiopulmonary bypass in patients with preserved right ventricular output. Int J Cardiovasc Imaging 2019;35:1661-70.
28. Gozdzik A, Letachowicz K, Grajek BB, Plonek T, Obremska M, Jasinski M, *et al*. Application of strain and other echocardiographic parameters in the evaluation of early and long-term clinical outcomes after cardiac surgery revascularization. BMC Cardiovasc Disord 2019;19:189.
29. Howard-Quijano K, Salem A, Barkulis C, Mazor E, Scovotti JC, Ho JK, *et al*. Preoperative three-dimensional strain imaging identifies reduction in left ventricular function and predicts outcomes after cardiac surgery. Anesth Analg 2017;124:419-28.
30. Abuelkasem E, Wang DW, Omer MA, Abdelmoneim SS, Howard-Quijano K, Rakesh H, *et al*. Perioperative clinical utility of myocardial deformation imaging: A narrative review. Br J Anaesth 2019;123:408-20.
31. Ternacle J, Berry M, Alonso E, Kloeckner M, Couetil JP, Randé JL, *et al*. Incremental value of global longitudinal strain for predicting early outcome after cardiac surgery. Eur Heart J Cardiovasc Imaging 2013;14:77-84.
32. Modin D, Sengeløv M, Jørgensen PG, Bruun NE, Olsen FJ, Dons M, *et al*. Global longitudinal strain corrected by RR interval is a superior predictor of all-cause mortality in patients with systolic heart failure and atrial fibrillation. ESC Heart Fail 2018;5:311-8.
33. Madhavan S, Chan SP, Tan WC, Eng J, Li B, Luo HD, *et al*. Teoh 6 Cardiopulmonary Bypass Time: Every Minute Counts J Cardiovasc Surg (Torino) 2018;59:274-81.
34 Salsano A, Giacobbee DR. Aortic cross clamp time and CPB time, prognostic implication in patients operated for IE Interactive CardioVascular and Thoracic Surgery 2018;27:328-35.
35. Bilgehan Erkut and Azman Ates. Investigation of the Effect of Cross-Clamp Time and CrossClamp Time on Troponin I Levels in Patients Undergoing Elective Coronary Artery Bypass Surgery. World Journal of Surgery and Surgical Research 2019:2;10-14.
36. Singh A, Huang X. RV function is reduced during cardiac surgery independent of procedural characteristics, reoperative status or pericardiotomy. The Journal of Thoracic and Cardiovascular Surgery 2020;159:430-8.