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Original Article

Evaluation of Left Ventricular Myocardial Work Performance in Patients Undergoing On-Pump and Off-Pump Coronary Artery Bypass Surgery

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Purpose: Benefits of off-pump coronary bypass (OPCAB) over on-pump (ONCAB) remain controversial. We aimed to evaluate the early impacts of OPCAB vs ONCAB for varying left ventricular (LV) function baselines by applying the non-invasive myocardial work (MW) analysis, which enables further insights in cardiac mechanics, contractility, and efficacy.
Methods: We retrospectively analyzed 98 patients (55 ONCAB vs 43 OPCAB). Transthoracic echocardiography (TTE) and concurrent arterial blood pressure measurements taken at rest, prior to, and early after surgery were performed. Global myocardial work index (GMWI), global constructive work (GCW), and global work efficiency (GWE), inter alia, were quantified.
Results: Preoperatively, OPCAB patients had significantly lower values than ONCAB patients in terms of GMWI (1404.33 ± 585.41 mmHg% vs 1619.07 ± 535.42 mmHg%, $p = 0.039$), GWE (90% (60%, 96%) vs 93% (74%, 98%), $p = 0.028$). After surgery, GMWI was reduced in both groups. However, a more significant GMWI impairment occurred early after ONCAB than after OPCAB (–343.14 ± 35.20 mmHg%, p <0.001 vs –224.04 ± 120.91 mmHg%, $p = 0.042$).
Conclusion: Despite lower preoperative LV function in OPCAB patients, GMWIs after OPCAB were superior to ONCAB, indicating better preservation of systolic LV function early after OPCAB by means of contractility compared to ONCAB. Further studies should investigate the long-term course of MW response and their clinical impact.

Keywords: echocardiography, non-invasive, global myocardial work, off-pump coronary surgery, left ventricular systolic function

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Introduction

The effectiveness of coronary artery bypass grafting (CABG) for the prognosis of multivessel and left main coronary artery disease has been proven.[1,2] Conventional, aortocoronary bypass (ONCAB) technique has been performed with the use of cardiopulmonary bypass (CPB). To minimize postoperative complications induced by CPB and cardioplegia, off-pump coronary artery bypass (OPCAB) grafting was introduced three decades ago.[3–8] However, the myocardial protection benefits of OPCAB and its impacts on early postoperative left ventricular (LV) performance remain controversial. Moreover, only few studies analyzed and compared changes in systolic left ventricular function (sLVF) after OPCAB and ONCAB.[9,10] Most commonly, biplane volumetric left ventricular ejection fraction (LVEF) is solely used to define sLVF. However, the accuracy and reproducibility of biplane-LVEF measurement remain dependent on image quality/acquisition, operator skills, and loading conditions.[11,12] The assessment of myocardial function by means of speckle tracking has been proposed to overcome these problems but is still has load dependency as a major limitation.[13,14] Invasively obtained LV pressure–volume loops provide accurate assessment of hemodynamic parameters of myocardial performance by evaluating contractility, elastance, and efficiency.[15] Recently, Russell et al.[16] introduced a novel non-invasive method to measure myocardial work (MW) using two-dimensional speckle tracking echocardiography (2D-STE) strain and non-invasively estimated LV pressure curves. Russel et al. demonstrated the validity of non-invasive MW based on LV pressure–strain loop with the invasive measured MW estimated from pressure–volume loop.[16,17] MW measurements take myocardial deformation as well as afterload into account; therefore, it is superior to 2D-STE and EF methods and provides additional information about myocardial functionality.[16,18,19]

In the present study, we used this novel non-invasive method to assess myocardial performance and LV contractility, comparing preoperative and postoperative changes in two different operative strategies, OPCAB and ONCAB, for myocardial revascularization.

Materials and Methods

Data source

Patient's data including demographics, clinical outcome, perioperative process, postoperative course, imaging, and laboratory data were retrospectively collected from our institutional database. The study was approved by the local ethical board (Ethikkommission-RWTH Aachen, IRBP 10/2014, EK151/09-Version-1.3). Due to the retrospective nature of our study, informed consent was waived by our institutional ethical board.

Study cohort

In this single-center, retrospective, observational study, adult patients (>18 years) who underwent isolated, elective CABG in our department between January 1, 2018 and March 30, 2019 were screened. Exclusion criteria included the following: combined procedures, emergency or urgent procedures, arrhythmia, pacemaker, aortic or mitral valve disease, hypertrophic cardiomyopathy with obstruction of LV outflow tract, history of prior cardiac surgery, severe peripheral artery disease and inaccurate acoustic window resulting in poor transthoracic echocardiography (TTE) image quality preoperatively or postoperatively. TTEs were performed by qualified echocardiographers.

The study cohort was divided into two groups. The ONCAB group consisted of 55 patients and the OPCAB group of 43 patients, respectively.

Echocardiographic analysis and measurements of LV parameters

TTE is routinely performed for all our patients. All patients underwent preoperative and postoperative standardized TTE according to American Society of Echocardiography (ASE) and the European Association of Cardiovascular Imaging (EACVI).[14,20] TTE was performed the day before operation and early after surgery at a median of 7 days postoperatively. Patients were scanned in the left lateral decubitus position with standard 2D images consisting of three cardiac cycles triggered to the QRS complex saved in cine-loop digital format for offline analysis. All echocardiography studies were performed using the Vivid E9 (GE Vingmed Ultrasound AS, Horton, Norway) and the measurements were done with EchoPAC version BT 202 (GE Vingmed Ultrasound AS).

Complete offline analysis for the assessment of the LV was performed accordingly by an expert. These included M-mode, 2D and tissue-Doppler imaging (TDI) as well as 2D-STE. Biplane EF of the LV was measured using the Simpsons method from apical four-chamber (A4C) and apical two-chamber (A2C) views. Peak systolic global longitudinal strain (GLS) of the LV was indicated as an average value from the three standard apical views. The timing of aortic and mitral valve opening and closure were determined by continuous wave Doppler. The brachial-cuff systolic pressure was measured immediately prior to each patient echocardiographic process. Global myocardial work index (GMWI), global constructive work (GCW), global wasted work (GWW), myocardial work efficiency (MWE = GCW/(GCW + GWW)) were calculated using a specific commercially available processing software package (GE Vivid E90 with the EchoPAC workstation) (**Fig. 1**) based on the described method by Russell et al.[16] TTE studies and analyses were performed by experienced and certified physicians.

Surgical technique

Decision on operative technique was made after team evaluation of the cases in our daily departmental

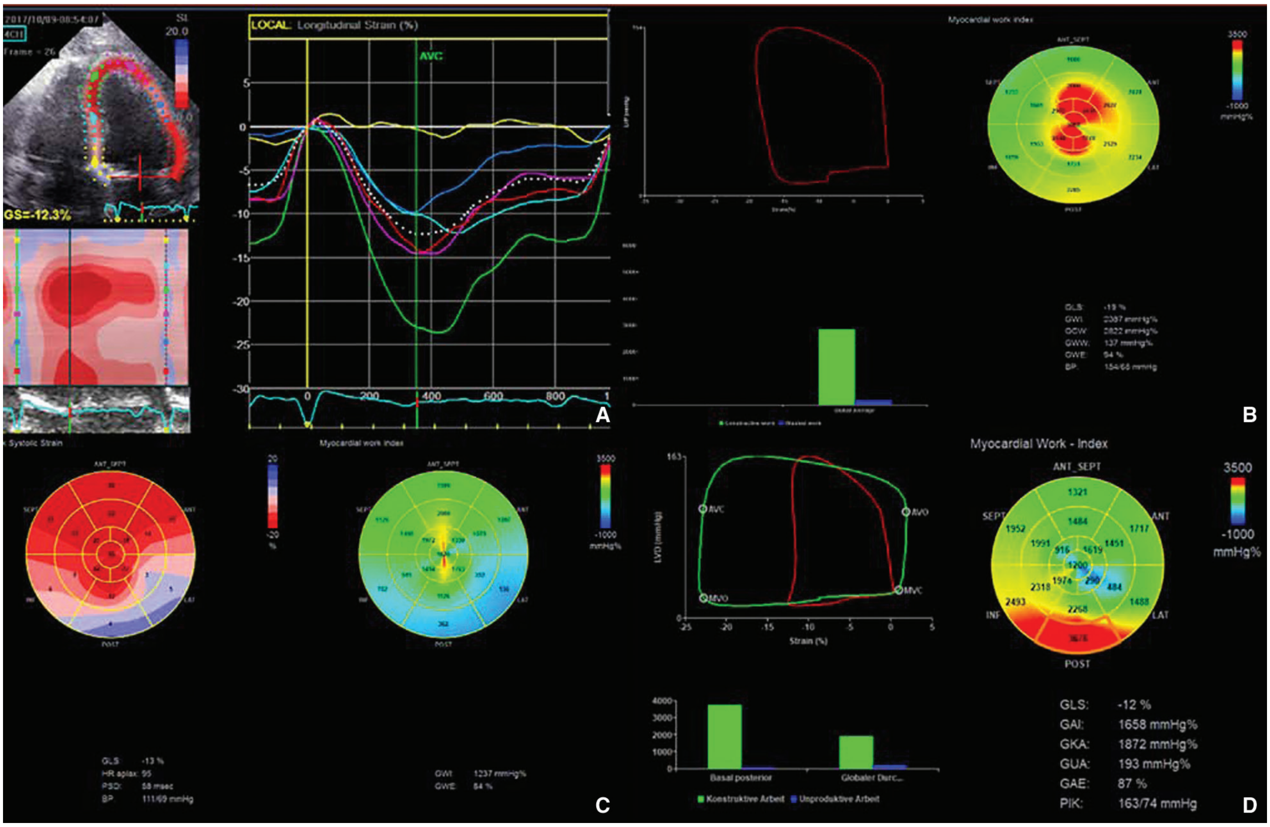


Fig. 1 Exemplary demonstration of selected echocardiography deformation imaging analysis. (**A**) GLS of LV, measured in 4CH view, (**B**) GMWI estimation (bull's eye), (**C**) peak systolic strain and GMWI bull's eye, and (**D**) regional and global MWI estimation. The GMWI bull's eye shows areas of negative work as blue, green indicates normal values while red shows areas of high work. GLS: global longitudinal strain; GMWI: global myocardial work index; LV: left ventricle; MWI: myocardial work index

meeting. Our practice is to perform OPCAB surgery, if deemed possible, in all multimorbid patients with prior cerebrovascular events, porcelain aorta, or severely reduced LV systolic function, presumed that the anatomy and quality of the target vessels, and the intraoperative tolerance of hemodynamic changes induced by heart positioning permit OPCAB performance. The final decision-making was left to the surgeon's preference. In both strategies, OPCAB and ONCAB, left internal mammary artery was used to bypass the left descending artery and vein grafts to bypass all other targets.

Monitoring, induction, and anesthesia were standardized for all patients. This included the use of transesophageal echocardiography (TEE). In both groups, patients received a complete revascularization and a transit-time flowmeter was used for the intraoperative control of the quality of the target vessel coronary anastomosis. All patients received the same postoperative intensive and intermediate care management.

ONCAB Group

Under weight-adjusted full heparinization, CPB was instituted using standard cannulation techniques (single-arterial and two-stage venous). Systemic temperature was kept between 34 °C and 36 °C. After aortic cross-clamping, myocardial protection was achieved using a cold single shot of antegrade Bretschneider crystalloid cardioplegia, with a doses of 1mL/minutes per gram of myocardium, in a temperature between 5 °C and 8 °C, at an initial perfusion pressure of 80–100 mmHg (perfusion pressure was maintained at 80–90 mmHg after diastolic arrest induction), over 6–8 minutes in all patients.

OPCAB Group

For OPCAB, all the patients received the same techniques for the exposure and lifting of the heart, and the stabilization and shunting of the target coronary vessel. Visualization, target vessel exposure, and hemostasis as well as coronary anastomosis were enhanced with the use of the same technique. An intracoronary shunt was used in all distal anastomosis. The order of revascularization was LIMA to LAD grafting, followed by inferior and marginal coronary branches.

Statistical analysis

All statistical analyses were performed using SPSS statistical software, version 25.0 (SPSS Inc., Chicago, IN, USA). Figures were made using Graph Pad Prism version 7.0a for MAC OS X (Graph Pad Software, La Jolla, CA, USA). The Kolmogorov–Smirnov test was used to assess the normal distribution of the continuous variables. Continuous variables are expressed as the means ± standard deviations (SDs) or as medians (minimum, maximum) if they were non-normally distributed. Categorical variables are expressed as absolute numbers and percentages. Comparisons between groups were performed with two-tailed Student's t-tests for normally distributed non-repeated continuous variables and with the Mann–Whitney U test for non-normally distributed continuous variables. Continuous repeated variables were analyzed with the two-way analysis of variance (ANOVA) test for the comparison between and within groups. Categorical variables were analyzed with a chi-square test or, if appropriate, Fisher's exact test. p values were reported as three-digit numbers or with at least one nonzero digit. A p value < 0.05 was considered statistically significant.

Results

Baseline, procedural, and clinical characteristics

In all, 324 patients were screened and 226 patients had to be excluded due to the following reasons: 76 patients had atrial fibrillation postoperatively, 6 patients had pacemaker implanted postoperatively, 38 patients had severe peripheral disease, 17 patients had prior cardiac surgery, preoperative TTE performed in our department revealed moderate aortic stenosis in 31 patients and moderate aortic regurgitation in 9 patients, 12 patients had moderate mitral regurgitation, and 37 patients had inaccurate image quality. The final cohort comprised of 98 patients.

All patients had an uneventful surgery. No conversion from OPCAB to ONCAB or other procedures occurred. Among the 98 studied patients in our cohort, 55 (56.1%) underwent ONCAB, and 43 (43.9%) underwent OPCAB surgery. The mean age of all patients was 67.28 ± 9.4 years. The detailed data for the entire cohort are included in **Table 1**. The two groups were well matched by means of age, body mass index (BMI), gender, and preoperative comorbidities. As expected, patients in the OPCAB group had higher European system for cardiac operative risk evaluation (EuroSCORE) II compared to ONCAB group (2.27 [1.10, 26.69] vs 1.10 [0.54, 3.15], $p = 0.003$).

In the ONCAB group, the total bypass duration time was 98.64 ± 24.22 minutes, and the average cross-clamp time was 62.62 ± 18.54 minutes.

All patients were clinically and hemodynamically stable and received evidence-based medical therapy in their early phase after surgery. No instances of acute myocardial infarction (MI) or neurological injury occurred. Regarding the immediate postoperative complications, there was one case of re-exploration surgery due to bleeding in each group. Maximal creatine kinase myocardial band (CK-MB) peak activity within the first 24 hours after surgery showed no significant differences between the groups. Duration of mechanical ventilation did not differ between ONCAB and OPCAB groups (6 ± 2 hr. vs 5.5 ± 1.5hr, $p = 0.175$, respectively). Intra-aortic balloon pump was required in one patient in the OPCAB group postoperatively, due to cardiogenic shock. In both groups, no patient required extracorporeal membrane oxygenator treatment (**Table 1**). There were no differences in the incidence of major adverse cerebral and cardiovascular events (MACCEs), acute kidney injury (AKI), sepsis, or 30-day mortality (**Table 1**).

Echocardiographic findings

Summary of all preoperative and postoperative changes in echochardiographic measurements between and within the groups are presented in **Table 2** and **Fig. 2**

Comparison of baseline (OPCAB vs ONCAB)

Preoperatively, OPCAB patients had significantly lower values than the ONCAB patients in terms of the GMWI (1404.33 ± 585.41 mmHg% vs 1619.07 ± 535.42 mmHg%, $p = 0.039$), global work efficiency (GWE; 90% [60%, 96%] vs 93% [74%, 98%], $p = 0.028$), LVEF (47.52 ± 14.00% vs 55.72 ± 10.23%, $p = 0.004$) and stroke volume index (SVI; 21.94 ± 7.39 mL/m^2 vs 27.31 ± 9.93 mL/m^2, $p = 0.026$) (**Table 2** and **Fig. 2**). Additionally, OPCAB patients had significantly higher GWW compared to ONCAB group (169.92 ± 95.12 mmHg%, vs 109.37 ± 64.65 mmHg%, $p = 0.006$).

Table 1 Baseline and procedural characteristics of ONCAB and OPCAB groups

Variables	ONCAB (n = 55)	OPCAB (n = 43)	*p* value
Age (years)	66.23 ± 9.13	69.08 ± 8.04	0.217
Male sex	46.00 (83.63)	33.00 (76.74)	0.990
BMI	26.14 (19.25, 45.00)	26.18 (19.81, 35.43)	0.901
BSA	1.96 ± 0.19	1.90 ± 0.16	0.301
Hypertension	36.00 (65.45)	34 (79.06)	0.243
Diabetes	15.00 (27.27)	12.00 (27.9)	0.561
Current smoker	12.00 (21.81)	22 (51.16)	**0.003**
COPD >II	1.00 (1.81)	2.00 (4.65)	0.408
Stroke	0.00	0.00	_
Peripheral vascular disease	7.00 (12.72)	11.00 (25.58)	0.116
Cerebral vascular disease	11.00 (20.00)	6.00 (13.95)	0.593
STEMI	4.00 (7.27)	3.00 (6.97)	1.000
NSTEMI	15.00 (27.27)	21.00 (48.83)	**0.034**
NYHA >II	20.00 (36.36)	15.00 (34.88)	1.000
Previous cardiac surgery	2.00 (3.63)	0 (0)	0.505
Previous stent implantation	11.00 (20.00)	1.00 (2.32)	0.081
Single vessel disease	2.00 (4.65)	6.00 (13.95)	0.073
Double vessels disease	9.00 (16.36)	14.00 (32.55)	0.059
Triple vessels disease	44.00 (80.0)	22.00 (51.16)	0.005
EuroSCOREII II	1.10 (0.54, 3.15)	2.27 (1.10, 26.69)	**0.003**
CPB time, in minutes	98.64 ± 24.22	_	_
Clamp time, in minutes	62.62 ± 18.54	_	_
All cause death	0 (0)	0 (0)	_
Reintubation	1.00 (1.81)	1.00 (2.32)	1.000
MV duration in hours	6 ± 2	5.5 ± 1.5	0.175
Re-exploration	1.00 (1.81)	1.00 (2.32)	1.000
MACCE	0.00 (0)	0.00 (0)	_
Cardiogenic shock	0.00 (0)	2.00 (4.65)	0.180
Sepsis	2.00 (3.63)	2.00 (4.65)	1.000
need of IABP	0	1 (2.3)	0.431
AKI	2.00 (3.63)	1.00 (2.32)	1.000
AV-Block	0	1.00 (2.32)	0.481
CK-MB peak activity (U/L)	43.67 ± 30.23	30.49 ± 45.03	0.100
Postoperative ICU stay (days)	2.00 (0.00, 21.00)	2.00 (1.00,112.00)	0.670

*Categorical data are presented as number (%). Continuous data are presented as median (interquartile range), and year is shown also with the standard deviation. Plus, minus values are means ± SD. Percentages may not sum to 100 because of rounding. AKI: acute kidney injury; BMI: body mass index; BSA: body surface area; CK-MB: creatine kinase myocardial band; COPD: chronic obstructive pulmonary disease; ECMO: extra corporeal membrane oxygenation; IABP: intra-aortic balloon pump; ICU: intensive care unit; MACCE: major adverse cerebral and cardiovascular events; MV: mechanical ventilation; NSTEMI: non-ST-elevation myocardial infarction; NYHA: New York Heart Association; ONCAB: on-pump coronary artery bypass grafting; OPCAB: off-pump coronary artery bypass grafting; STEMI: ST-elevation myocardial infarction

Neither GLS (−13.54±5.14% vs −15.48 ± 4.62%, p = 0.055) nor GCW (1648.92 ± 658.75 mmHg% vs 1808.60 ± 551.60 mmHg%, p = 0.240) did differ between the two groups preoperatively.

Echocardiographic changes within each group

In the ONCAB group, significant reduction in GMWI GCW, SVI, GLS, and LVEF was documented postoperatively (p <0.001, p <0.001, p = 0.016, p <0.001, p = 0.023) (**Table 2**, **Fig. 2**). Postoperatively, GWW did not increase significantly (p = 0.078) within the ONCAB group (**Table 2**, **Fig. 2**).

In the OPCAB group, postoperative values of GWE, GCW, SVI, and left ventricular end-diastolic index (LVEDVi) did not differ significantly compared to the baseline (**Table 2**). While GMWI and GLS decreased significantly after surgery (mean difference −224.04 ± 120.91 mmHg%, p = 0.042; −1.79 ± 1.09%, p = 0.016, respectively), and the GWW value increased significantly (p = 0.028) (**Table 2**, **Fig. 2**).

Table 2 Comparison of echocardiographic changes between and with the groups

	Pre-op			Post-op			ONCAB			OPCAB		
	ONCAB	OPCAB	*p* value	ONCAB	OPCAB	*p* value	Pre-op	Post-op	*p* value	Pre-op	Post-op	*p* value
GMWI	1619.07 ± 535.42	1404.33 ± 585.41	**0.039**	1275.93 ± 570.65	1180.29 ± 464.50	0.421	1619.07 ± 535.42	1312 ± 576	**<0.001**	1404.33 ± 585.41	1180.29 ± 464.5	**0.042**
GCW	1808.06 ± 551.60	1648.92 ± 658.75	0.240	1513.08 ± 608.79	1524.70 ± 497.82	0.988	1808.60 ± 551.60	1553 ± 604	**0.004**	1648.92 ± 658.75	1524.70 ± 497.82	0.473
GWW	109.37 ± 65.65	169.92 ± 95.12	**0.006**	164.81 ± 111.66	228.24 ± 168.13	**<0.01**	109.37 ± 64.65	164 ± 107	0.078	169.92 ± 95.12	228.24 ± 168.13	**0.028**
GWE	93 (74, 98)	90 (60, 96)	**0.028**	88 (31, 99)	85 (55, 96)	0.498	93 (74, 98)	88 (31, 99)	**<0.001**	90 (60, 96)	85.00 (55, 96)	0.111
SVI	27.31 ± 9.93	21.94 ± 7.39	**0.026**	25.16 ± 7.10	20.50 ± 6.48	0.941	27.31 ± 9.93	25.16 ± .10	**0.016**	21.94 ± 7.39	20.50 ± 6.48	0.964
LVEDVi	50.74 ± 13.78	50.52 ± 12.87	0.557	48.32 ± 12.95	50.42 ± 14.30	0.687	50.74 ± 13.78	48.32 ± 12.95	**0.038**	50.52 ± 12.87	50.42 ± 14.30	0.889
LVEF	50.77 ± 11.34	47.55 ± 12.24	**0.004**	50.77 ± 11.34	47.55 ± 12.24	0.498	55.72 ± 10.23	50.77 ± 11.34	**0.023**	47.52 ± 14.00	47.55 ± 12.24	0.972
GLS	−15.48 ± 4.62	−13.54 ± 5.14	0.055	−12.64 ± 4.09	−11.75 ± 4.05	0.588	−15.48 ± 4.62	−12.64 ± 4.09	**<0.001**	−13.54 ± 5.14	−11.75 ± 4.05	**0.023**

GCW: global constructive work (%mmHg); GLS: global longitudinal strain (%); GMWI: global myocardial work index (%mmHg); GWW: global wasted work (%mmHg); GWE: global work efficiency (%); LVEDI: left ventricular end-diastolic index; LVEF: left ventricular ejection fraction (%); Pre-op: preoperative; Post-op: postoperative; SVI: stroke volume index

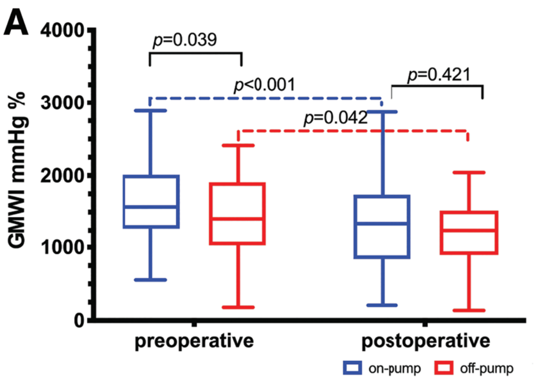
Comparison between the groups (OPCAB vs ONCAB)

After surgery, GMWI values were reduced in both groups. However, a more significant GMWI impairment was detected early after ONCAB than after OPCAB (mead differences preoperative vs postoperative: −343.14 ± 35.20 mmHg%, p <0.001 vs −224.04 ± 120.91 mmHg%, p = 0.042) (**Table 2**, **Fig. 2**). The GWE, GCW, SVI, and LVEF values were significantly preserved after OPCAB but reduced significantly after ONCAB (−5% [−5%, 0%), p = 0.111 vs −5% [− 1%, −43%] p <0.001, −124.22 ± 160.93 mmHg% p = 0.473 vs −295.52 ± 57.19 mmHg%, p = 0.004, −1,44 ± 0.91 mL/m^2, p = 0.964 vs −2.15 ± 0.07 mmHg%, p = 0.016, −0.03 ± 1.76%, p = 0.972 vs −5.05 ± 1.11%, p = 0.023). Interestingly, the GWE and SVI values were proven to be maintained after OPCAB, even with the significantly inferior baseline values.

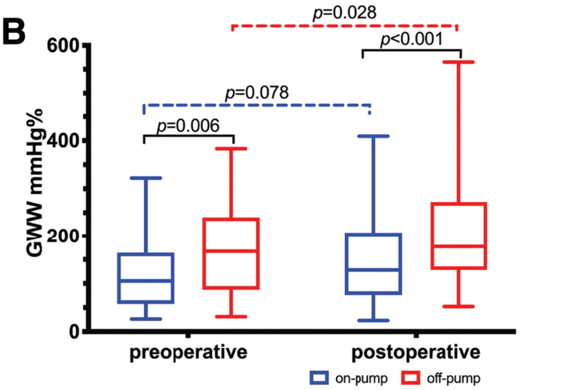
Despite significant difference in baseline MW parameters and conventional echocardiographic measurements (**Table 2**, **Fig. 2**), postoperatively only GWW values remained significantly higher in the OPCAB group than in the ONCAB group (228.24 ± 168.13 mmHg%, vs 164.81 ± 111.66 mmHg%, p <0.001), while GMWI, GCW, GWE, GLS, and EF remained similar between the two groups.

Discussion

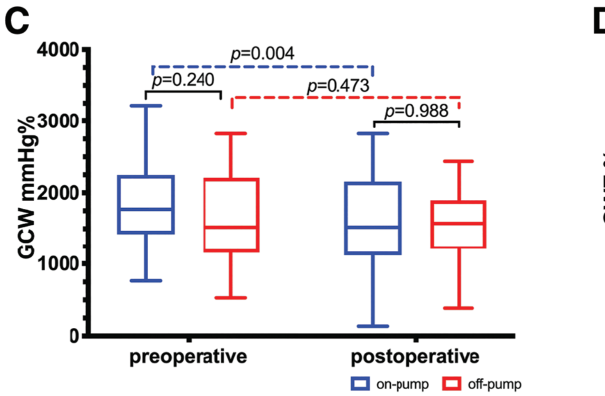
The utility of OPCAB has been well described, but its effects on sLVF have not been thoroughly investigated. To the best of our knowledge, our study is the first based on the non-invasive MW method to evaluate the early effects of ONCAB and OPCAB surgery on sLVF in patients with both normal and abnormal baseline LV function. Non-invasive assessment of myocardial performance remains a challenging topic. Deformation imaging using 2D-STE myocardial is a valuable tool, enabling extensive quantitative assessment of myocardial function far beyond EF.[21,22] Nonetheless, a major limitation of STE is its load dependency, which affect the accuracy of myocardial function evaluation.[23] Contrarily, the novel non-invasive MW measurement takes into account both deformation changes and afterload, therefore offers potentially incremental value to myocardial function evaluation.[16,24] Non-invasive GMWI did find clinical implications in many areas. Edwards et al.[25] found that non-invasive GMWI is sensitive to metabolic adaptation of the myocardium in the presence of CAD. Findings by Edwards et al.[25] are promising and demonstrated the possible use of non-invasive MW analysis as clinical



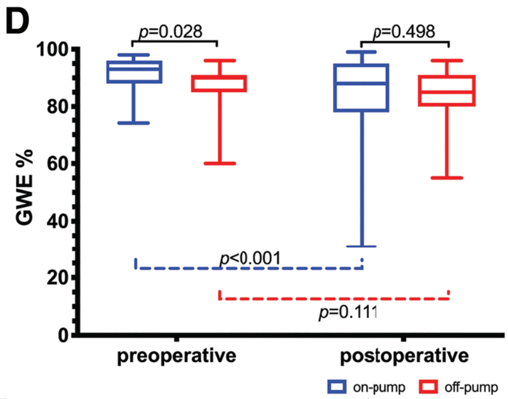
ANOVA table	SS	DF	MS	F (DFn, DFd)	P value
Time x Column Factor	212580	1	212580	F (1, 96) = 1.189	P=0.2783
Time	3761861	1	3761861	F (1, 96) = 21.04	P<0.0001
Column Factor	1870548	1	1870548	F (1, 96) = 4.699	P=0.0326
Subject	38212374	96	398046	F (96, 96) = 2.226	P<0.0001



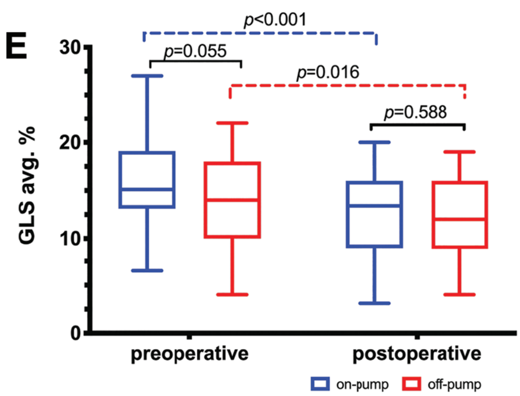
Fixed effects (type III)	P value	P value summary	Statistically significant (P < 0.05)?	F (DFn, DFd)
Time	0.0015	**	Yes	F (1, 95) = 10.72
Surgery	<0.0001	****	Yes	F (1, 96) = 16.73
Time x Surgery	0.6386	ns	No	F (1, 95) = 0.2221



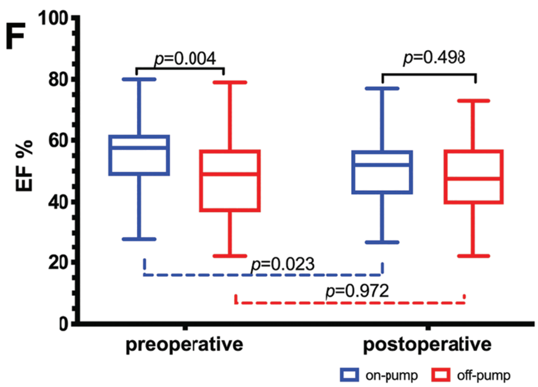
Fixed efects (type III)	P value	P value summary	Statistically significant (P < 0.05)?	F (DFn, DFd)
Time	0.0043	**	Yes	F (1, 95) = 8.558
Surgery	0.3338	ns	No	F (1, 96) = 0.9435
Time x Surgery	0.2029	ns	No	F (1, 95) = 1.644



ANOVA table	SS	DF	MS	F (DFn, DFd)	P value
Time x Column Factor	185.9	1	185.9	F (1, 96) = 3.349	P=0.0703
Time	1234	1	1234	F (1, 96) = 22.23	P<0.0001
Column Factor	415.7	1	415.7	F (1, 96) = 3.087	P=0.0821
Subject	12927	96	134.7	F (96, 96) = 2.426	P<0.0001



ANOVA table	SS	DF	MS	F (DFn, DFd)	P value
Time x Groups	14.04	1	14.04	F (1, 96) = 1.734	P=0.1910
Time	229.1	1	229.1	F (1, 96) = 28.31	P<0.0001
Groups	92.49	1	92.49	F (1, 96) = 2.920	P=0.0907
Subject	3041	96	31.68	F (96, 96) = 3.914	P<0.0001



ANOVA table	SS	DF	MS	F (DFn, DFd)	P value
Time x Column Factor	295.5	1	295.5	F (1, 88) = 5.658	P=0.0195
Time	234.1	1	234.1	F (1, 88) = 4.482	P=0.0371
Column Factor	1243	1	1243	F (1, 88) = 5.193	P=0.0251
Subject	21063	88	239.4	F (88, 88) = 4.583	P<0.0001

Fig. 2 Comparison of echocardiographic values between the groups and within each group, before and after surgery. Two-way ANOVA table: Each F ratio is computed by dividing the MS value by another MS value. The MS value for the denominator depends on the experimental design. ANOVA: analysis of variance; DF: degrees of freedom; F: ratio; MS: mean square; PI: pulse index; rpm: revolution per minute; SS: the sum-of-squares

diagnostic utility for early detection of CAD. Previous study by Chan et al.[26] demonstrated the use of non-invasive MW measurements as diagnostic tool in ischemic and non-ischemic cardiomyopathies. Non-invasive MW analysis has been used in resynchronization therapy to predict responders, who would benefit from resynchronization device therapy.[27]

In our study, MW assessment revealed differences in both baseline and postoperative sLVF that even SVI and GLS, failed to detect.

In summary, OPCAB proved to preserve sLVF postoperatively, despite lower baseline sLVF compared to ONCAB. The combination of the unchanged sLVF after OPCAB and the significantly reduced sLVF after ONCAB eliminated the sLVF baseline disadvantage of OPCAB patients, resulting in a similar postoperative LV performance for both groups. Our findings confirm the hypothesis that OPCAB surgery provides better preservation of sLVF compared to ONCAB early after surgery.

In our study, the two groups were well matched in terms of the preoperative and perioperative characteristics. Patients in the OPCAB group had a significantly higher EuroSCOREII than patients in the ONCAB group, mainly due to the high outlier scoring rather than to the mean. Within the ONCAB group, all patients received the same cardioplegic agent administered by the same technique. Within the OPCAB group, the same surgical technique was applied. Myocardial injury biomarkers (CK-MB) showed no significant differences between the two groups. This suggests that our results reflect real differences between ONCAB and OPCAB surgery more than patient heterogeneity of the two groups despite the small sample numbers.

GWE reflects the energy consumed by LV and is reduced in cases of reduced sLVF.[18] GCW estimation allows the assessment of sLVF during the systolic and isovolumic relaxation phase. GWW reflects the energy loss, by means of work that is being produced by the ventricle, but does not contribute to LV ejection and represents a measure of contractile reserve.[28]

There was a significant alter in MW indices in both groups postoperatively. Baseline GWW values proved to be higher within the OPCAB group than in the ONCAB group and continued to extend significantly after OPCAB, while no significant difference occurred after ONCAB. Hence, consequently, as GWW reflects the viable myocardium, it is possible that the higher viable myocardial reserve within the OPCAB group than within the ONCAB group might explain in part the better preservation of LV contractility.[17] In contrast, any such advantage of myocardial recovery may be temporary outweighed by the myocardial changes induced by cardioplegia during ONCAB surgery. There is evidence that cardioplegic arrest, perioperative ischemia, reperfusion injury, myocardial stunning, and hibernation trigger ultrastructural and biochemical myocardial changes that persist for hours, days, or even weeks.[29] There is a variable recovery time course of the viable myocardium because dysfunctional segments can demonstrate different stages of structural abnormalities.[30,31]

Only few preexisting studies have thoroughly inspected sLVF changes early after revascularization. Diller et al.[32] showed that sLVF was not affected within the first 5 days after CABG, even in patients with preserved preoperative myocardial function and independently of the surgical technique (ONCAB and OPCAB). This was a small study based only on tissue Doppler imaging, which is an angle-dependent method necessitating apnea during recording.[32] Letsou et al. proved that sLVF, as assessed by LVEF, improved early after OPCAB and beating heart on-pump surgery.[33] Koene et al. were the first to prove a significant decrease in sLVF by means of LVEF after ONCAB in patients with normal preoperative LVEF and an increase in those with poor baseline LVEF 3 months after surgery.[34] These studies lacked comparison data between ONCAB and OPCAB and referred to another follow-up period.

Our study proved an acute impairment of sLVF by terms of GMWI and MWE reduction early after both ONCAB and OPCAB surgery, tended, however, to be significantly extended after ONCAB. Substantial improvements in sLVF are often noted as early as 3–5 days after OPCAB revascularization techniques.[33,35] One explanation for sLVF recovery was described by Letsou et al.,[33] and they showed that CABG did increase the myocardial oxygen supply to formerly ischemic myocardial, while having no further damage to non-ischemic well-perfused myocardium.[33] The avoidance of ischemic myocardial arrest (and possibly the resultant myocardial edema) might be the most essential factor in the early regeneration of myocardial function after OPCAB.

Our findings support the advantages of OPCAB over ONCAB in the sLVF preservation, in the absence of clinical impact at this early stage.

Limitations

Due to the retrospective nature of our study, our analysis was prone to potential bias in patient selection and data acquisition. As a notable limitation, myocardial protection was performed with crystalloid cardioplegia in this study. The postoperative differences documented in our study between the groups may considerably be lower using intermittent blood cardioplegia in the ONCAB cohort, although there were no significant postoperative differences in myocardial injury by means of enzyme profiles.

LV pressure estimation based on the arterial systolic pressure measured by the brachial-cuff sphygmomanometer might be imprecise due to variation in the arterial tree. Central systolic pressure is lower than peripheral systolic pressure due to aortic augmentation. However, in our study, we already excluded all patients with aortic stenosis, LV outflow-tract hypertrophy with obstruction, and any other cardiac pathologies that could induce a pressure gradient between aorta and LV. A further important limitation is the effect of heart rate variability and arrhythmia on MW measurements, significant beat-to-beat variability, can lead to an inaccurate assessment of GLS by 2D-STE, therefore making MW estimation questionable in such patients. In our study, we also did exclude patients with atrial fibrillations and other arrhythmias. After cardiac surgery with sternotomy, it is difficult to obtain enough acoustic window. Other factors such as obesity and pulmonal emphysema also limit the quality of TTE imaging. Reduction of ultrasound frequency to 1.5 Mhz or lower increased image quality in patients with poor acoustic windows, but at the cost of lateral resolution. Interestingly, sufficient speckle-tracking can be achieved even in med-quality TTE images, as commercial algorithms are able to resort to variability of spline smoothing using available information from the strongest ultrasound signals. Myocardial recovery appears at various stages; hence, our findings exhibit the evaluation of the sLVF at the early postoperative period, no long-term conclusion, can be drawn based on our results. Further studies of the regional and global MW parameters in larger cohorts with long-term follow-up are required.

Conclusion

Despite lower preoperative LV function in OPCAB patients, GMWIs after OPCAB were greater compared to ONCAB patients. Our finding indicates the superiority of OPCAB in sLVF preservation over ONCAB. Further studies should investigate the long-term changes in global and regional MW parameters and their clinical impact.

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Disclosure Statement

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