


Off Pump-Functional Complete Coronary Revascularization: Correlation between Preoperative and Postoperative Systolic Left Ventricular Function and Wall Motion Score Index

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Abstract

Background: Current study aims to evaluate outcomes after complete coronary revascularization and correlate outcomes with systolic left ventricular functions to assess effectiveness and significance of complete functional revascularization during off-pump coronary artery bypass grafting. **Methods:** Between 1st Jan 2023 and 30th Dec 2024, we received: 1) Fifty patients with ischemic hypokinetic one or more left ventricular segments (group-1 with hypokinesia) and 2) Fifty patients with severe hypokinetic segments and reduced segmental wall thickness (group-2 with severe hypokinesia and reduced wall thickness). Complete functional coronary re-vascularization was performed for all. They had echo-cardiography preoperatively, before hospital discharge, one, six and 12 months postoperatively. During this prospective cohort study, two patients had urgent postoperative coronary angiography. **Results:** Statistically significant differences between study groups regarding age and distribution of the degrees of stenosis. Age showed significant negative inverse correlation with preoperative systolic left ventricular functions. The degree of stenosis showed direct positive correlation with wall motion score and score index. Fifty percent of the patients in group-1 had 75% - 90% coronary artery stenosis, whereas 50% in group-2 had >90% stenosis. Left ventricular systolic functions showed statistically significant differences between preoperative and postoperative assessments during the study within both groups and between both

groups. Significant direct positive correlation coefficient between ejection Fraction (EF) and mitral annular plane systolic excursion (MAPSE) measurements, as well as wall motion score and score index measurements. During the first 6 months of follow-up, there was a weak correlation between wall motion score and ejection fraction. Post-operative wound infection was recorded in 5 cases in both study groups. Myocardial infarction occurred in one case of group 1 and 2 cases of group 2. The two patients who had urgent postoperative coronary angiography, each had left internal mammary artery-to-left anterior descending graft stenosis, percutaneous coronary intervention with drug-eluting stent was an effective option. **Conclusion:** Complete off-pump functional surgical revascularization is highly recommended as it reverses ischemic myocardial changes; It is a significantly worthy recommendation that off pump is a safer and less invasive technique than on pump technique.

Keywords

Complete Coronary Revascularization, Off-Pump Coronary Artery Bypass Grafting, L.V. Wall Motion Abnormality-Score-Index, Systolic Left Ventricular Functions, CMRI and Systolic Left Ventricular Functions

1. Introduction

Complete revascularization: is defined as successful revascularization of all coronary lesions or segments > 1.5 mm in diameter with >50% arterial diameter stenosis [1]. Angiography-based assessment remains the standard of care [2].

Types of Complete revascularization:

1) Anatomic revascularization may be declared complete if all stenotic vessels are revascularized, irrespective of size and supplied territory; other investigators impose minimum diameter criteria, whereas other researchers differentiate between main vessels and branch vessels [3]. Thus, complete anatomic revascularization:

-Unconditional: All stenotic vessels are revascularized, irrespective of size and supplied territory.

-Conditional: All stenotic vessels greater than a defined diameter are revascularized, all stenotic main-branch vessels are revascularized, irrespective of myocardial viability.

2) Complete functional revascularization: All ischemic myocardial territories are going to be re-perfused except areas of old infarction with no viable myocardial tissues.

3) Complete numeric revascularization is obsolete [3].

Left ventricular ejection fraction (LVEF) is an important indicator of systolic left ventricular function and of the severity and prognosis of ischemic heart disease. Assessment of regional function using the wall motion score index (WMSI) may be an alternative means of evaluating left ventricular function. Coronary artery calcification is a marker of plaque development and provides direct evidence

of the extent of coronary artery disease burden. Also, it can predict future cardiovascular events [4].

Multi-vessel coronary artery disease presents a clinical challenge in management and decision making. Guidelines provide some reference points, but some areas of uncertainty remain such as the strategy for intermediate stenotic artery lesions and the approach to preserve left ventricular functions.

The aim of the current study is to correlate between complete functional revascularization and left ventricular systolic functions before and after Off Pump CABG surgery.

2. Methods

This prospective Cohort study included 100 patients. They were divided into two groups based on degree of wall motion abnormality: Group-1 included 50 patients with ischemic hypokinetic one or more left ventricular segments. Group-2 included 50 patients with severe hypokinetic segments and reduced segmental wall thickness.

They had off-pump complete functional coronary artery revascularization. We used bilateral skeletonized internal mammary arteries as grafts. Also, endoscopically harvested long saphenous vein grafts were applied.

The concomitant presence of myocardial ischemia, stunning or hibernating myocardium may complicate appraisal of left ventricular (LV) functions. Several imaging modalities have been recruited for the accurate assessment of left ventricular myocardial wall motion, wall thickness, viability, and stunning. We applied repeated trans-thoracic echocardiography (2D, 3D) and Multi-slice CT-angiography to assess left ventricular functions.

The left ventricle is divided as follows: basal segments, mid segments and apical segments.

Each segment is then scored, using the following criteria:

- (1 point) Normo-kinetic: normal wall thickening and normal endocardial excursion
- (2 points) Hypokinesia: reduced wall thickening, reduced endocardial excursion
- (3 points) Akinesia: absence of either wall thickening or endocardial excursion
- (4 points) Dyskinesia: systolic outward stretching or thinning. It includes “aneurysmal” wall motion, which bulges eccentrically during both systole and diastole [1].

The wall motion score index is calculated by dividing the sum of the segmental values by the number of myocardial segments = 16.

A WMSI of 1.0 (16/16) is considered normo-kinetic and correlates with echocardiographic (3D) calculated ejection fraction of 64%, whereas a WMSI of 3.0 correlates with an ejection fraction of 12% and is considered akinetic. WMSIs of 1.5, 2.0, and 2.5 indicate mild hypokinesia, hypokinesia, and severe hypokinesia respectively. WMSI is a superior predictor of 12-month-mortality over LVEF in STEMI patients treated with primary PCI. When examined in multivariable pre-

dictive models, WMSI and LVEF perform very well at predicting 12-month mortality [2] [3].

Sample Size: calculated according to the Equation:

$$N = 2\{(Z_{a/2} + Z_B) \times a\}/(U_1 - U_2)\}^2 \text{ (Dawson \& Trapp., 2004) [4]}$$

N = Sample size

$Z_{a/2}$ = The critical value that divides the central value 95% of the Z distribution from the 5% in the tail = 1.96

Z_B = The critical value that separates the lower 20% of the Z distribution from the upper 80% = 0.64

U_1 = Incidence of symptomatic coronary artery disease = 40% of patients attending our clinics.

U_2 = Incidence of significant multiple vessel disease indicating surgical intervention = 15% of patients attending our clinics.

Sample size was calculated based on detecting a 5% absolute improvement in LVEF after CABG, assuming a standard deviation of 10% with expected difference in means = 0.05 and power = 80%.

So, after adding 10% drop-out patients during follow up, the sample size will be 100 patients. This is sufficient to detect a clinically significant difference between the two groups.

Inclusion criteria:

Multivessel coronary artery disease, hemodynamically stable patients who are candidates for complete revascularization, men or women and age below 70 years.

Exclusion criteria:

- 1) Hemodynamically unstable patients
- 2) Cardiogenic shock
- 3) Complications such as aneurysm score (wall motion score 4),
- 4) moderate to severe or severe mitral regurgitation or ischemic interventricular septal defect.
- 5) Severely calcified lesions.
- 6) Associating valvular severe lesions or lesions indicating cardiac surgical procedures besides CABG.
- 7) Conduction of cardiac action potential-abnormalities that may result in dyssynchronous contraction, simulating a true decrease in the contractile function of the myocardium, left bundle branch block.
- 8) Patients having In-Stent Restenosis (ISR).
- 9) Diffuse coronary artery disease.
- 10) Deep intramyocardial or calcified coronaries.

They had preoperative, 6-months and one-year postoperative echocardiography (TTE), Multi-slice CT-coronary angiography, myocardial perfusion Imaging or angiography. Also, they had echocardiography on discharge & one month later.

Each patient had complete functional revascularization with off-pump CABG: 176 stenotic lesions (group 1) and 180 severe stenoses and occlusive lesions (group 2) which indicated 356 distal anastomoses. Although we believe that completeness

of revascularization is more important than the use of on-pump or off-pump technique, we did not need to shift any case from off-pump to on-pump technique.

Statistical Section:

Data was fed to the computer and analyzed using IBM SPSS software package version 24.0. (Armonk, NY: IBM Corp).

We used the mean values and the standard deviation and estimated the P value Also, the correlation coefficient for different variables in both groups A, B1 & B2 and the correlation coefficient for preoperative and postoperative data.

The correlation coefficient is a statistical measure of the strength of a linear relationship between two variables. Its value can range from -1 to 1 . A correlation coefficient of -1 describes a perfect negative (inverse) correlation, with values in one series rising as those in the other are declining, and vice versa. A coefficient of 1 shows a perfect positive correlation, or a direct relationship. A correlation coefficient of 0 means there is no linear relationship. Correlation coefficients are used to assess the strength of associations between data variables. The “Pearson correlation coefficient,” measures the strength and direction of a linear relationship between two variables. Values always range from -1 for a perfectly inverse, or negative, relationship to 1 for a perfectly positive correlation. Values at or close to zero indicate no linear relationship or a very weak correlation. The coefficient values required to signal a meaningful association depend on the application. The statistical significance of a correlation can be calculated from the correlation coefficient and the number of data points in the sample, assuming a normal population distribution.

To calculate the Pearson correlation, start by determining each variable’s standard deviation as well as the covariance between them. The correlation coefficient is covariance divided by the product of the two variables’ standard deviations.

$$\rho_{xy} = \text{Cov}(x, y) / \sigma_x \sigma_y$$

where: ρ_{xy} = Pearson product-moment correlation coefficient (x, y) = covariance of variables x and y;

σ_x = standard deviation of x;

σ_y = standard deviation of y [5].

3. Results

Between Jan.2023 and Dec.2024, we received fifty-patients with ischemic hypokinetic one or more left ventricular segments, stenotic lesions $> 50\%$ reduction in diameter in 176 vessels (group 1) and fifty-patients: some with severely hypokinetic segments, reduced left ventricular wall thickness in 75 vessels and severe stenotic lesions $> 90\%$ in 105 vessels (group2), $P < 0.05$ (**Table 1**). Off-pump complete re-vascularization was performed for each patient. Bilateral internal mammary arteries and endoscopically harvested long saphenous venous grafts were anastomosed to stenotic vessels.

The serial left ventricular systolic functions measured preoperatively, one, six and 12 months postoperatively showed that:

There was a statistically significant difference between study groups regarding

age (**Table 1**). Most of the study's participants in both groups were males. Less than one third of the study population were non-smokers. Most of the study participants had at least one 1st degree relative who had a history of ischemic heart diseases (**Table 1**). There were no statistically significant differences between study groups regarding the status of being diagnosed with diabetes and/or hypertension. It can be noted for both groups that the patients with hypertension were less than the normo-tensive in number (**Table 1**).

Table 1. Characteristic features for both groups.

Table 1: Is showing age, social and medical distribution of the study population				
Variable		group 1	group 2	p-value
Age (years) - Mean \pm SD		49.22 \pm 4.47	53.1 \pm 5.88	0.001*
Variable	Attribute	n (%)	n (%)	
Sex	Men	27 (54)	32 (64)	0.309
	Women	23 (46)	18 (36)	
Smoking index	Not smoking	6 (12)	10 (20)	0.065
	<20 pack year	23 (46)	12 (24)	
	20 or more pack year	21 (42)	28 (56)	
Family history	No	10 (20)	7 (14)	0.545
	One person	21 (42)	26 (52)	
	2 Persons	16 (32)	12 (24)	
	3 Persons	3 (6)	5 (10)	
Diabetes	No	41 (82)	40 (80)	0.799
	Yes	9 (18)	10 (20)	
Hypertension	No	27 (54)	33 (66)	0.221
	Yes	23 (46)	17 (34)	

*There is statically significant difference; The table above shows that: there is a statistically significant difference between study groups regarding age. There is no statistically significant difference between study groups regarding gender, smoking index, family history of CAD or the status of being diagnosed with diabetes and/or hypertension.

Most of the study participants in both groups had 3 lesions, with a statistically significant difference between both study groups regarding the number of lesions. Patients in group 1 had 75% - 90% stenosis, whereas most of the patients in group 2 had > 90% stenosis. There was a statistically significant difference between both study groups regarding the distribution of the degrees of stenosis (**Table 2**). There was a significant difference between study groups regarding the number of distal anastomoses (**Table 2**).

Regarding ejection fraction: there were statistically significant differences between the measurements of ejection fraction done at the 3 time points in the study within each group. Moreover, there were statistically significant differences between the study groups regarding each measurement recorded for both groups

(Table 3).

Mitral annular plane systolic excursion (MAPSE) changes in the study population: there were statistically significant differences between the measurements of MAPSE done at the preoperative and one-year post-operative assessments. Moreover, there were statistically significant differences between both study groups regarding each measurement recorded for both (Table 3).

Table 2. Table showing preoperative vascular properties.

Variable	Group	1	2	p-value
	Results	n (%)	n (%)	
Number of lesions	3	33 (66)	42 (84)	0.038*
	4	17 (34)	8 (16)	
Degree of stenosis	50% - 74%	4 (8)	0 (0)	<0.001*
	75% - 90%	46 (92)	0 (0)	
	91% - 99%	0 (0)	21 (42)	
	Complete occlusion	0 (0)	29 (58)	
Total Number of distal anastomoses	3	33 (66)	44 (88)	0.009*
	4	17 (34)	6 (12)	

*The value is statistically significant, The number of lesions equals the number of distal anastomoses.

Regarding wall motion score-changes (WMS) in the study population: there were statistically significant differences between the measurements of WMS done at the preoperative and one-year post-operative examination within both groups. Moreover, there was a statistically significant difference between both studied groups regarding only the preoperative measurement recorded for both groups (Table 3). Wall motion score index changes in the study population: there were statistically significant differences between the measurements of WMSI done at the preoperative study and one-year post-operative measurements within each group. Moreover, there were statistically significant differences between both study groups regarding each measurement recorded at the 3 time points in the study (Table 3).

Post-operatively, wound infection was recorded in a few cases in both study groups. Myocardial infarction occurred in one case of group 1 and 2 cases of group 2. Mortality was recorded in group 2 for 3 cases: two due to deteriorated left ventricular functions as a result of complicated moderate to severe mitral regurgitation, and the third had a dissecting aneurysm & renal failure and died. There was statistically non-significant difference between both study groups regarding wound infection, post-operatively occurring myocardial infarction and mortality (Table 4). Preoperative and postoperative Echocardiographic data correlation coefficient: (Table 5) showed significant direct positive correlation coefficient between ejection fraction and mitral annular plane excursion-measurements. Sig-

nificant negative inverted correlation relationship between age, EF, wall motion score and score index measurements. Weak non-significant correlation coefficient between preoperative MAPSE and one-year EF, as well as the wall motion score and wall motion score index at one-year postoperative measurements also between both preoperative and one-year postoperative data. A positive family history correlates positively with the severity of CAD and number of stenotic vessels. Two patients had urgent postoperative coronary angiography. Each had left internal mammary artery-to-left anterior descending graft stenosis, percutaneous coronary intervention with drug-eluting stent was an effective option.

Table 3. Left Ventricular systolic functional changes during the progress of the study, mitral annular plane systolic excursion changes in the study population.

Variable	Mean ± SD-Group 1	Mean ± SD-group 2	p-value
EF - Preoperative (%)	45.84 ± 0.85	38.98 ± 1.9	<0.001
EF - one-month post-operative (%)	54.54 ± 1.53	47.59 ± 2.3	<0.001
EF - one-year post-operative (%)	62.29 ± 4.49	70.11 ± 1.58	<0.001
Preoperative/postoperative change	<0.001	<0.001	---
MAPSE preoperative	8.92 ± 0.97	7.08 ± 0.75	<0.001
MAPSE - one-year post-operative	12.96 ± 1.03	11.74 ± 1.08	<0.001
Pre-post change	<0.001	<0.001	---
WMS - preoperative	24.9 ± 1.66	32.38 ± 3.42	<0.001
WMS - one-year post-operative	18.44 ± 2.19	19.09 ± 1.92	0.100
Pre-post operative change	<0.001	<0.001	---
WMSI - Preoperative	1.73 ± 0.17	2.96 ± 0.62	<0.001
WMSI - one-year	1.13 ± 0.11	1.27 ± 0.07	<0.001
Pre-post change	<0.001	<0.001	---

EF: Ejection fraction changes in the study population; MAPSE: mitral annular plane systolic excursion changes in the study population; WMS: wall motion Score, WMSI: wall Motion Score Index.

Table 4. Is showing post-operative morbidity and mortality.

Variable	Group outcome	Group		p-value
		1 n (%)	2 n (%)	
Wound infection	No	48 (96)	47 (94)	0.646
	Yes	2 (4)	3 (6)	
MI - one-month	No	49 (98)	48 (96)	0.558
	Yes	1 (2)	2 (4)	
Mortality	No	50 (100)	47 (94)	0.079
	Early	0 (0)	3 (6)	
	Late	0 (0)	0 (0)	

Table 5. Preoperative and postoperative echocardiographic and cardiac MRI -data correlation coefficient.

	EF - Preoperative (%)	EF - one month (%)	EF - one year (%)	MAPSE preoperative	MAPSE - one-year	WMS - preoperative	WMS - one-year	WMSI - Preoperative
EF - one month (%)	0.791*							
EF - one year (%)	0.420*	0.506*						
MAPSE preoperative	0.641*	0.669*	0.156					
MAPSE - one-year	0.403*	0.342*	0.219*	0.511*				
WMS - preoperative	-0.737*	-0.795*	-0.525*	-0.570*	-0.298*			
WMS - one-year	-0.131	-0.189	0.004	-0.245*	-0.207*	0.165		
WMSI - Preoperative	-0.691*	-0.722*	-0.484*	-0.538*	-0.466*	0.835*	0.226*	
WMSI - one-year	-0.480*	-0.563*	-0.515*	-0.401*	-0.168	0.587*	0.07	0.638*

EF: Ejection fraction changes in the study population; MAPSE: mitral annular plane systolic excursion changes in the study population; WMS: wall motion Score, WMSI: wall Motion Score Index.

4. Discussion

The primary goal is to manage myocardial ischemia as early as possible. The preventive approach is to revascularize stenotic lesions as early as reduction in diameter of the coronary artery to >50% to prevent myocardial infarction. There is growing evidence in support of coronary complete revascularization [6] [7]. Completeness outweighs the technique, off-pump or on-pump [7].

Complete coronary revascularization may be categorized as anatomic (revascularization of all lesions of at least 50% or 70% in vessels of at least 1.5 or 2 mm in diameter) or functional (revascularization of all ischemia-producing lesions). The beneficial effect of complete revascularization on clinical outcomes has been shown in a randomized trial of patients with ST-segment elevation myocardial infarction: complete anatomic revascularization lowered the incidence of adverse cardiovascular events compared with culprit vessel-only revascularization [8]. The anatomic definition of complete revascularization (CR) that defines territories at risk as those with an angiographic definition of significant obstruction. Although a functional definition also exists, researchers did not find evidence-based substantial differences between anatomic and functional complete revascularization [9] [10]. Others, however, found differences only in those receiving functional revascularizations such as the 2021 study by Veiga Oliveira *et al.*, which directly compared definitions and outcomes in the same cohort of patients and reported only an advantage to functional revascularization (Hazard Risk 0.47, 95% CI 0.23 to 0.97, $p = 0.041$) [11]. They reported that: complete surgical revascularization has different definitions but with the same impact. We got comparable results when we applied complete conditional anatomical, numeric revascularization with Off-pump CABG. We excluded cases with left ventricular dyskinesia [12]. Dyskinesia score is (4 points) including systolic outward stretching or thinning. It includes “aneurysmal” wall motion abnormality, which bulges eccentrically during both systole and diastole [1]. In a clinical trial cohort of 1147 patients

who underwent CABG, 810 (70.6%) received complete revascularization (CR). The primary outcome was a composite of major adverse cardiac events (MACEs), including death from any cause, nonfatal myocardial infarction, or repeat revascularization over a median 4.7 years of follow-up. MACE occurred in 175 patients (21.6%) in the complete revascularization group and 86 patients (25.5%) in the incomplete revascularization (IR) group (hazard ratio [HR] 0.87, 95% confidence interval [CI] 0.67 to 1.13, $p = 0.29$). A total of 12.0% in the CR group and 14% in the IR group died (HR 0.93, 95% CI 0.65 to 1.32, $p = 0.67$); nonfatal myocardial infarction occurred in 6.0% in the CR group and 9% in the IR group (HR 0.76, 95% CI 0.48 to 1.2, $p = 0.24$), and repeat revascularization occurred in 8% in the CR group and 12% in the IR group (HR 0.64; 95% CI 0.42 to 0.95, $p = 0.027$) [13]. Authors in the REGROUP trial concluded that in patients with a great burden of co-morbidities who underwent CABG in the REGROUP trial over a median follow-up period of 4.7 years, CR was associated with similar MACE rates but a reduced risk of repeat revascularization [14]. Complete revascularization was superior to culprit-only revascularization. It was associated with a reduction in cardiovascular death or myocardial infarction. It also improved patient-reported health status. This was accomplished without an increase in major bleeding or contrast-induced nephropathy [15].

We are reporting similar mortality and morbidity after complete revascularization as one-year outcome. Mortality and morbidity showed non-significant differences between our groups. Age showed significant negative inverse correlation relationship with left ventricular functions in these patients with coronary artery disease. Age is a non-modifiable risk factor in the progress of atherosclerosis. CAD prevalence increases after 35 years of age in both men and women. A positive family history correlates positively with the severity of coronary artery stenosis and number of lesions. A positive family history is a significant risk factor in the initiation of atherosclerosis. Patients with a family history of premature cardiac disease younger than 50 years of age have an increased CAD mortality risk [15]. There was a weak correlation between wall motion score, one year after revascularization and the ejection fraction at the three times of examination. Ejection fraction correlates well with left ventricular wall motion score index. This means improvement or even normalization of all ischemic areas after complete revascularization. Our study excluded cases with aneurysmal scars of myocardium.

Limits:

Limited follow-up period 12 ± 1.1 months, small sample size and one Centre Study.

5. Conclusion

Complete off-pump functional surgical revascularization is highly recommended as it reverses ischemic myocardial changes; This is evidenced by progressive improvement in systolic left ventricular functions and wall motion score and score indices over time. Completeness outweighs the technique, off-pump or on-pump. It is a significantly worthy recommendation that off pump is a safer and less inva-

sive technique.

Complete Statements and Declarations

All Authors contributed equally to finalizing this article. All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Hamdy. Dosoky. Elayouty, Hassan. Salah Hassan and Hamed, Mohamed Sami. The acquisition, analysis and interpretation of data for the work as well as the first draft of the manuscript was written by Ahmed Hamdy. Elayouty. El-Fark, Magdy Mohamed Omar revised the draft. All authors commented on previous versions of the manuscript. All authors read and approved the final submitted manuscript. They approved the current version of the manuscript and agreed for publication. Each author agrees to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Registration of the Study

This study was approved and registered by the Research and Research ethical Committee in Faculty of Medicine, Suez Canal University. The Number for registration is (4472/11/02/2021). *This panel includes authors and Statesian*, based on their expertise in the development of clinical practice documents, is trying to establish a uniform methodology for joint society' s projects. The writing panel collaborated to draft all document sections that were reviewed and discussed during several committee meetings. Consensus was achieved in every phase throughout the development process of this study

The Data Availability Statement

Data Available on Request: the data underlying this article will be shared at a reasonable request to the corresponding author.

The URL

<https://docs.google.com/document/d/1cCcG-DruFFzwqHHI3zLR8yPIf5lBnMwJE/edit?usp=drivesdk&oid=112024197390049416959&rtpof=true&sd=true>.

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Ethical Considerations

This study was approved by the Research and Research ethical Committee in Faculty of Medicine, Suez Canal University. The Number for registration is (4472/11/02/2021). *This panel including authors and Statesian*, based on their expertise in the development of clinical practice documents, is trying to establish

a uniform methodology for joint society's projects. The writing panel collaborated to draft all document sections that were reviewed and discussed during several committee meetings. Consensus was achieved in every phase throughout the development process of this study.

We received written informed consent from each participant. All patients were informed and accepted to participate in this study.

Conflicts of Interest

The authors declare that no conflicts of interest exist.

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