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A single center's experience with total arterial revascularization and spiral aneurysmorrhaphy for ischemic cardiac disease

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Abstract

The restoration of left ventricular (LV) geometry in combination with coronary artery bypass grafting for the treatment of ischemic cardiac disease remains controversial. We hereby present the experience of our center with total arterial myocardial revascularization (TAMR) and spiral aneurysmorrhaphy for ischemic heart disease. A retrospective analysis of 101 patients with advanced cardiovascular disease who underwent TAMR and spiral aneurysmorrhaphy was performed. Spiral aneurysmorrhaphy is a modification of the linear aneurysmorrhaphy and was applied to patients who had a LV aneurysm with a diameter of less than 5 cm. Peri-operative and in-hospital data were retrieved. The majority of the patients were male (87.13%) with a mean age of 63.1 years. Mean pre-operative ejection fraction (EF) was 35.7% ranging between 20 and 65%. An average of 3.23 grafts was required per patient. Early mortality was 6.93% (one intra-operative and six in-hospital deaths). Addition of concomitant valve surgery was associated with prolonged total operative, cardiopulmonary bypass and cross-clamp time ($p < 0.001$), increased need for blood ($p = 0.012$) and plasma ($p = 0.038$), longer intensive care unit (ICU) stay ($p = 0.045$) and higher rate of post-operative cerebrovascular accident ($p = 0.011$). Furthermore, patients with a pre-operative EF between 30 and 50% had a shorter ICU stay ($p = 0.045$) and LoS ($p = 0.029$) compared with patients with EF < 30%. Early mortality and post-operative complication rates following this combined procedure are in consistency with the relevant available data suggesting its feasibility regardless of the EF or addition of concomitant surgeries. Data from the follow-up of these patients are required to examine the long-term efficacy of this surgical modality.

Keywords Total arterial revascularization · Aneurysmorrhaphy · Ischemic heart disease · Left ventricular aneurysm

Introduction

The term "ischemic cardiomyopathy" was first introduced approximately half a century ago for characterization of a poorly functioning left ventricle as a result of myocardial ischemia [1]. According to Laplace's law, chamber enlargement due to ischemic remodeling leads to increased wall tension of the left ventricle (LV) [2]. This mechanical wall stress results in increased oxygen demand, hypoperfusion of the subendocardial heart tissue and decreased systolic LV function [2]. Results from the Coronary Artery Surgery Study (CASS) showed improved survival with surgery in heart failure patients with LV aneurysm and multi-vessel coronary artery disease [3]. The superiority of total arterial revascularization (TAMR) over coronary artery bypass grafting (CABG) with the use of vein grafts is prominent, therefore TAMR represents the optimal surgical modality for the treatment of advanced ischemic coronary artery disease [4, 5]. Coronary revascularization is considered a suitable option in patients with ischemic cardiomyopathy if the viability of the ventricle has remained intact. However, re-establishment of the coronary circulation alone may not be sufficient to reverse the remodeling process and restore the normal geometry of a ventricle that has undergone irreversible ischemic injury [6].

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For reconstruction of the LV, a variety of procedures have been proposed. Dor's procedure (use of a patch) is the most commonly used, followed by linear aneurysmorrhaphy [7]. Although Dor's procedure seems to be associated with better post-operative outcomes, it is an invasive and technically challenging technique [8]. On these grounds, we suggest a modification of the linear aneurysmorrhaphy which could be utilized for the restoration of small-sized LV aneurysms with a diameter less than 5 cm. By this technique, the edges of the transition zone surrounding the scar tissue are brought together in a spiral manner. In this way, enhanced reinforcement of the suturing line is achieved when compared with the linear technique, while also avoiding the invasive nature of Dor's procedure.

Although a combination of CABG and LV reconstruction seems to be the optimal approach for advanced ischemic cardiac disease, this hypothesis was not validated by the STITCH trial [9], the first randomized control trial examining this rationale. On the other hand, data from large-scale registries [2] and case series from referral centers [10–12] are promising and suggest the application of this combined procedure.

Given the availability of various surgical modalities and the controversy of the existing literature, we sought to examine the feasibility of TMAR and spiral aneurysmorrhaphy in the treatment of ischemic heart disease.

Materials and methods

Study design

From April 2003 to December 2015, a total of 113 patients with advanced heart failure (New York Heart Association (NYHA) score of 3 or higher) due to ischemic cardiomyopathy were treated surgically at the Department of Cardiac Surgery, Euroclinic of Athens, Greece. Of them, 101 patients underwent spiral aneurysmorrhaphy for reconstruction of the left ventricle and total arterial revascularization(Fig. 1). 31patients presented with an aneurysm on the posterior surface of the left ventricle, while 70 patients had anterior aneurysm. Patient data including demographic characteristics, comorbidities, pre-operative diagnosis, pre-operative ejection fraction (EF), operative procedure and post-operative course during hospitalization were reviewed.

All surgeries were performed by the same surgeon (I.C.), so that confounding effects regarding surgeon's experience and skills will be avoided.

Total arterial revascularization

Criteria for revascularization were stenosis>60% and vessel diameter > 1.5 mm. Out of the total population, 91 patients underwent a complete revascularization. All the anastomoses
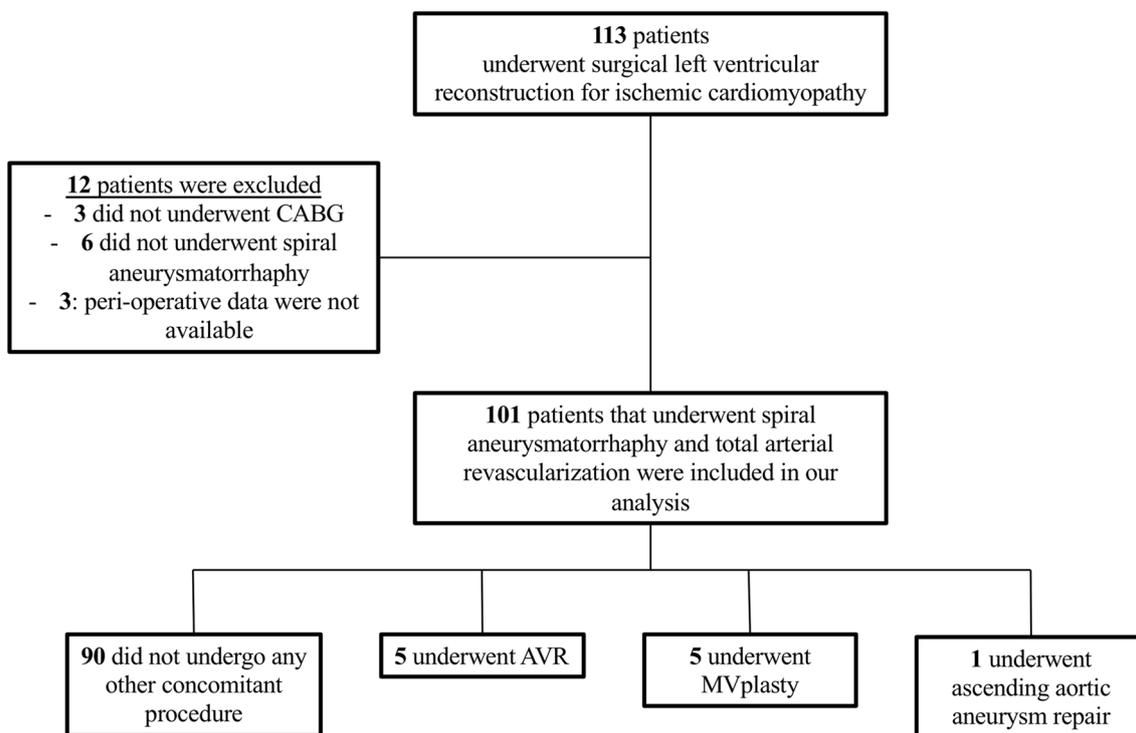

Fig. 1 Flowchart of the study. *CABG* coronary artery bypass grafting, *AVR* aortic valve replacement, *MV* Mitral valve

made are explicitly tabulated in Table 1. Briefly, left internal mammary artery (LIMA) was anastomosed to left anterior descending artery (LAD) in approximately half of the occasions (52.48%), while a sequential anastomosis of LIMA to diagonal branch (D) and LAD was performed in 14.85% of the patients. Right internal mammary artery (RIMA) was most commonly anastomosed to obtuse marginal branch (OM) (54.46%) and right posterior descending artery (RPDA) (13.86%). Left radial artery (LRA)–RPDA and LRA-–right posterolateral branch (RPL) anastomoses were performed in 30.69% and 11.88% of the cases, respectively. Right radial artery (RRA) was used in one patient and was anastomosed to RPDA. Moreover, IMAs were in situ, all RRAAs were to the aorta and the RIMA to OM was underneath the aorta.

Spiral aneurysmorrhaphy: surgical technique

This technique may be applied on pump for reconstruction of small aneurysms with a diameter less than 5 cm, whereas ventricles with larger aneurysms are opened and treated using Dor's reconstruction. Inferior left ventricular aneurysms were the result of the occlusion of dominant right coronary artery, while anterior aneurysms resulted from dominant left anterior descending coronary artery occlusion. First, we evacuate all blood from left ventricle through a needle vent inserted in the ascending aorta connected to a vent. When this vent is applied through the aortic valve into the left ventricular chamber, it forms a crater that reveals a transition zone. This transition zone borderlines the relatively normal thick myocardium from the infarcted area which is characterized by a whitish tissue that represents the thin scar. Most of the times vacuum forms a circular or elliptic transition line. Using the transition line as a guide, a double row purse string of 3–0 prolene is applied in an overcovered mode and then tied after release of the vacuum. Therefore, there is an approach of thick to thick myocardium and exclusion of the scar (Fig. 2). This very simple, not time-consuming and safe technique may contribute to a small decrease of left ventricular diameter. Yet, according to Laplace's law, even the smallest amount of decrease in the diameter of left ventricle may decrease the left ventricular wall tension. Moreover, when thick parts of non-infarcted myocardium are approximated, the left ventricular pressure is applied to a thicker wall. The law of Laplace principally states that "the tension within the wall of a sphere filled to a particular pressure depends on the thickness of the sphere. Consequently, even at a constant pressure, the tension within a filled sphere can be decreased simply by increasing the thickness of the sphere's wall". Thus said, it is essential to decrease the diameter and increase the thickness of the left ventricular wall to decrease the tension which may decrease oxygen consumption.

Statistical analysis

Distributions of the quantitative variables were evaluated for normality by the Shapiro–Wilk test. Continuous variables following normal distribution are expressed as mean ± standard deviation. Qualitative data are expressed as frequency.

Table 1 Anastomoses made between arterial grafts and coronary arteries

LIMA		RIMA		LRA		RRA		MIX	
LIMA–LAD	53/101	RIMA–LAD	4/101	LRA–LAD ×3	1/101	RRA–RPDA	1/101	LRA–LIMA–RCA	1/101
LIMA–LAD ×2	11/101	RIMA–OM	55/101	LRA–LPL	5/101				
LIMA–LAD ×3	1/101	RIMA–OM ×2	4/101	LRA–OM–RPL	1/101				
LIMA–D–LAD	15/101	RIMA–OM–D	2/101	LRA–OM ×2	6/101				
LIMA–D–LAD1–LAD2	1/101	RIMA–LPL	2/101	LRA–RPDA ×2	1/101				
LIMA–D	1/101	RIMA–LPL–LPDA	1/101	LRA–LPDA	2/101				
LIMA–OM	2/101	RIMA–RPL	4/101	LRA–OM	3/101				
		RIMA–RPDA	14/101	LRA–RCA	3/101				
		RIMA–RAMUS	1/101	LRA–RCA ×2	1/101				
		RIMA–RAMUS–OM	1/101	LRA–RPDA–RPL	3/101				
		RIMA–RCA	7/101	LRA–RPDA	31/101				
		RIMA–D–LAD	1/101	LRA–RPDA–LPL	1/101				
				LRA–RPL	12/101				

LIMA left internal mammary artery, *LAD* left anterior descending, *D* diagonal, *OM* obtuse marginal, *RIMA* right internal mammary artery, *LPL* left posterolateral, *LPDA* left posterior descending artery, *RPL* right posterolateral, *RCA* right coronary artery, *RPDA* right posterior descending artery, *RRA* right radial artery, *LRA* left radial artery

Fig. 2 Schematic of the spiral aneurysmorrhaphy technique. The first figure **a** illustrates the elliptic transition line formed by the vacuum and the application of the double row purse string in an overcovered mode intra-operatively. The second figure **b** represents the post-operative result of the spiral aneurysmor-rhaphy indicating the approach of the two edges of healthy myocardium. The third figure **c** represents the pre-operative aspect of the lesions with the fibrous scar of the left ventricular wall and akinesia. The fourth figure **d** represents the post-operative result of the spiral aneurysmorrhaphy indicating the approach of the two edges of healthy myocardium and exclusion of the scar tissue
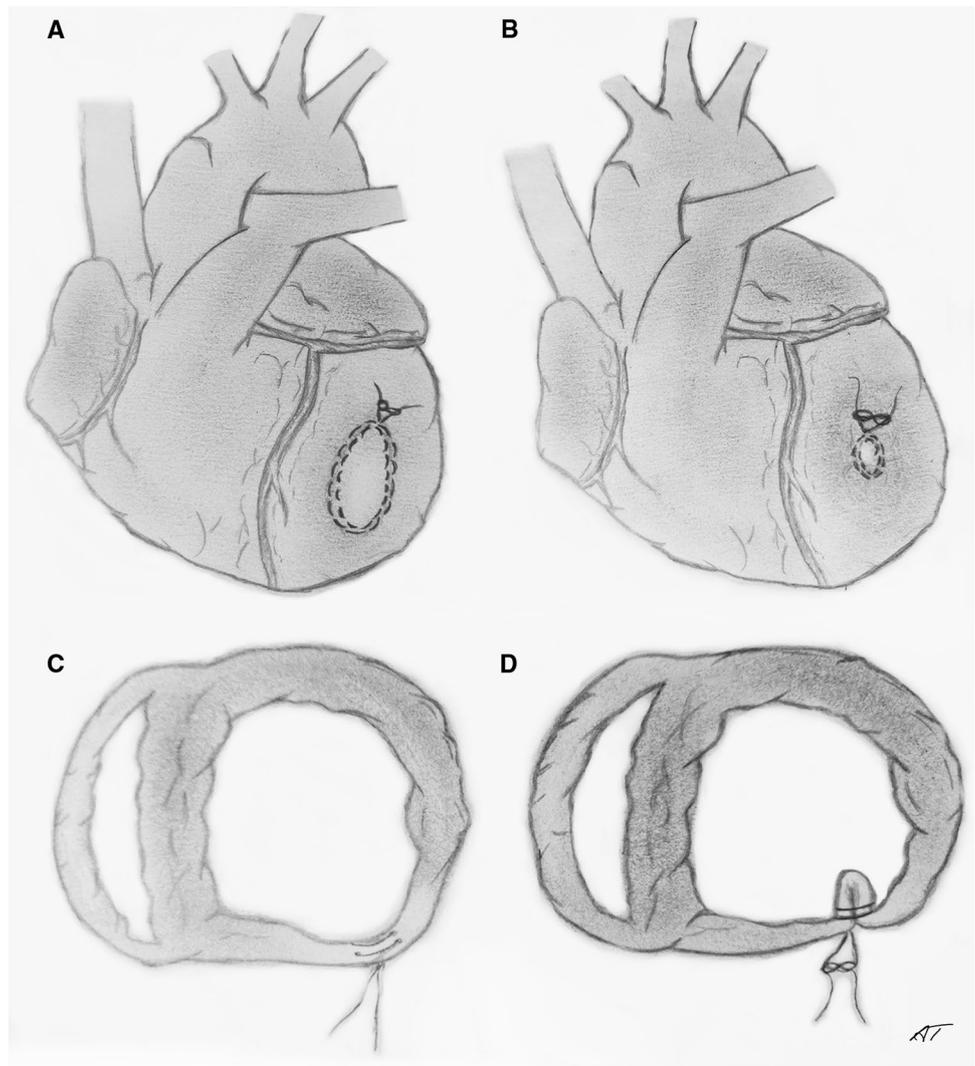
Chi-square test was used to determine whether there were non-random associations between the categorical variables in subgroups of the study population.

Linear regression models were implemented to examine the association of patients' demographics or peri-operative characteristics with clinical outcomes.

The correlation of ejection fraction with intra-operative characteristics as well as hospitalization data was calculated with the use of Pearson correlation coefficient.

All tests were two-sided and differences were considered as statistically significant if the null hypothesis could be rejected with >95% confidence interval ($p < 0.05$).

All statistical analyzes were conducted in SPSS (version 23 for Mac OS; SPSS, Inc., Chicago, IL, USA).

Ethical standards

The local ethics committee of Euroclinic of Athens approved our study which conformed to the ethical guidelines of the 1975 Declaration of Helsinki. Written informed consent by the patients was not required due to the retrospective nature of the study and the preservation of their anonymity.

Results

Patients' characteristics

Patients' demographics, comorbidities and pre-operative medications are tabulated in Table 2. Male gender was predominant (87.13%) and the mean age of the patients was 63.1 years (range 38–84 years). Mean EF was 35.7% ranging from 20 to 65%. Hypertension was the most common comorbidity with a prevalence of 69.66% followed by dyslipidemia (66.29%). Approximately, nine out of ten patients had a known history of myocardial infarction (90.63%), 14.13% had undergone PCI and 5.43% underwent a re-do CABG. At the time of admission, angina was present in 56.52% of

Table 2 Patients' demographics, comorbidities and pre-operative medications

Patient characteristics	n	%
Age (years), mean (SD), range	63.1 (8.9)	38–84
BMI (kg/m^2), mean (SD), range	26.2 (3.1)	18.9–40.1
Hypertension	62/89	69.66%
Diabetes	35/89	39.33%
Dyslipidemia	59/89	66.29%
Smoking	38/89	42.70%
PAD	5/88	5.68%
CVA	4/89	4.49%
Renal failure	6/89	6.74%
Previous MI	87/96	90.63%
Previous PCI	13/92	14.13%
Previous CABG	5/92	5.43%
Angina	52/92	56.52%
Anti-platelet	72/87	82.76%
Anti-coagulants	14/87	16.09%
Statins	36/87	41.38%
ACEi	44/87	50.57%
ARBs	13/87	14.94%
Loop	34/87	39.08%
Thiazide	6/87	6.90%
Beta-blockers	53/87	60.92%
CCB	27/87	31.03%
Nitrates	31/87	35.63%

Data are expressed as absolute and relative frequencies for qualitative variables and as mean–SD range for continuous variables

SD standard deviation, *BMI* body mass index, *PAD* peripheral artery disease, *CVA* cerebrovascular accident, *MI* myocardial infarction, *PCI* primary coronary intervention, *CABG* coronary artery bypass grafting, *ACEi* angiotensin-converting enzyme inhibitors, *ARBs* aldosterone receptor blockers, *CCB* calcium channel blockers

the cases. The majority of the patients were under treatment with anti-platelet agents (82.76%) and beta-blockers (60.92%).

Peri-operative data

As illustrated in Table 3, the patients of our study required more than three arterial grafts on average (mean: 3.23 grafts), while total operative time was approximately four hours (mean 250.4 min) and cross-clamp time an hour (mean 59.9 min). The need for transfusion required an average of 1.19 units of packed blood cells (PBC), 3.61 units of fresh frozen plasma (FFP) and 0.52 units of platelets. Patients developed low cardiac output syndrome (LCOS) in 8% of the cases and incident atrial fibrillation (AF) in a rate of 7%. All other observed complications had an incidence of less than 5%. Intra-aortic balloon pump was required in 15 (out of 100) patients. Median intensive care unit (ICU) stay was

48 h (range 32–288 h) and median length of stay (LoS) was 8 days (range 8–23 days). In the 101 patients who underwent SA with total arterial revascularization, the overall hospital mortality was 6.93% (*n* = 7). 30-day mortality was identical with in-hospital mortality. One patient died during surgery, while the other six during hospitalization 7.3 days post-operatively on average. Linear regression analysis did not reveal any correlation between pre-operative clinical variables and post-operative outcomes, except for previous CABG and ICU stay as well as CABG and LoS (*p* < 0.01 in both cases). When considering only patients that underwent cardiac surgery for the first time, the overall mortality was 6.25% (6/96).

Concomitant surgeries

Addition of mitral valve or aortic valve surgery was not associated with increased mortality rates (Table 3). Addition of concomitant surgery was associated with prolonged total operative, cardiopulmonary bypass and cross-clamp time (*p* < 0.001 in all cases). The need for PBC and FFP transfusion increased in the presence of concomitant surgery (*p* = 0.012 and *p* = 0.038, respectively). Post-operatively, the addition of a valve surgery led to a higher rate of CVA (*p* = 0.011) as well as a prolonged ICU stay (*p* = 0.045).

Ejection fraction

When comparing subgroups of the population with regard to their EF, a significant difference in mortality was not observed (Table 4). However, it should be noted that data for patients with a pre-operative EF between 30 and 50% had shorter ICU stay (*p* = 0.045) and LoS (*p* = 0.029) compared with patients with EF < 30%. As shown in Fig. 3, a significant inverse correlation was observed between ejection fraction and CPB time (*p* = 0.011), XC time (*p* = 0.028) and LoS (*p* = 0.022), while it was marginal in the case of total operative time (*p* = 0.070) and ICU stay (*p* = 0.089).

Discussion

Cooley et al. were the first to perform a successful LV aneurysm repair with the use of cardiopulmonary bypass 60 years ago [13]. Ever since, various surgical modalities have been introduced for the treatment of this entity [8]. Nowadays, Dor's procedure is the most commonly used, however, the benefit of LV reconstruction in addition to revascularization for the treatment of advanced ischemic myocardiopathy remains unclear 12/1/2018 4:44:00 PM [2]. Despite the promising data from the RESTORE SVR Registry [2] which showed excellent 5-year outcomes regarding the role of LV reconstruction in the treatment of ischemic heart disease,

Table 3 Intra- and post-operative data of all the patients

	Overall			CABG +SA		CABG +SA + concomitant surgery		p value
	n	%	Range	n	%	n	%	
Intra-operative data								
Number of vessels bypassed, mean(SD)	3.23	0.82	1–5	3.28	0.78	3.67	0.58	
1	2/101	1.98%		1/90	1.11%	1/11	9.09%	> 0.05
2	14/101	13.73%		10/90	11.11%	4/11	36.36%	> 0.05
3	49/101	48.04%		47/90	52.22%	2/11	18.18%	> 0.05
4	31/101	30.39%		28/90	31.11%	3/11	27.27%	> 0.05
5	5/101	4.90%		5/90	5.56%	0/11	0.00%	> 0.05
Total operative time (min), mean(SD)	231.7	46.2	125–335	225.7	41.7	311.7	25.2	< 0.001
CPB time (min), mean(SD)	90.7	32	45–190	84.95	24.6	166.7	20.2	< 0.001
XC time (min), mean(SD)	59.3	24.3	25–125	54.6	17.5	122.7	2.5	< 0.001
PBC, mean(SD)	1.19	1.92	0–11	1.03	1.83	1.33	1.83	0.012
FFP, mean(SD)	3.61	3.92	0–23	3.23	3.89	2.67	2.31	0.038
PLT, mean(SD)	0.52	2.02	0–12	0.15	0.95	0.08	0.95	0.076
Post-operative data								
Bleeding	1/101	0.99%		0/90	0.00%	1/11	9.09%	> 0.05
MI	1/101	0.99%		1/90	1.11%	0/11	0.00%	> 0.05
AF	7/101	6.93%		7/90	7.77%	0/11	0.00%	> 0.05
CVA	2/101	1.98%		0/90	0.00%	2/11	18.18%	0.011
Renal failure	3/101	2.97%		2/90	2.22%	1/11	9.09%	> 0.05
Pneumonia/respiratory failure	1/101	0.99%		1/90	1.11%	1/11	9.09%	> 0.05
Infection	4/101	3.96%		3/90	3.33%	1/11	9.09%	> 0.05
LCOS	8/101	7.92%		8/90	8.88%	0/11	0.00%	> 0.05
IABP	15/101	14.85%		12/90	13.33%	3/11	27.27%	> 0.05
ICD	0/101	0.00%		0/90	0.00%	0/11	0.00%	> 0.05
PCI	0/101	0.00%		0/90	0.00%	0/11	0.00%	> 0.05
Re-operation	1/101	0.99%		0/90	0.00%	1/11	9.09%	> 0.05
ICU stay (h), mean (SD)	73.3	71.8	32–288	41.2	17.1	38.4	8.8	0.045
LoS (d), mean (SD)	10.2	4.4	8–23	7.6	2	6.8	0.8	0.029
Intra-operative mortality	1/101	0.99%		1/90	1.11%	1/11	9.09%	> 0.05
In-hospital mortality	6/101	5.94%		4/90	4.44%	2/11	18.18%	> 0.05

Data are also presented separately for the patients who underwent solely CABG and SA as well as CABG, SA and concomitant surgery. p values refer to the comparison between CABG + SA vs CABG + SA + concomitant surgery. Data are expressed as absolute and relative frequencies for qualitative variables and as mean–SD range for continuous variables

CABG coronary artery bypass grafting, *SA* spiral aneurysmorrhaphy, *SD* standard deviation, *CPB* cardiopulmonary bypass, *XC* cross-clamp, *PBC* packed blood cells, *FFP* fresh frozen plasma, *PLT* platelets, *MI* myocardial infarction, *AF* atrial fibrillation, *CVA* cerebrovascular accident, *LCOS* low cardiac output syndrome, *IABP* intra-aortic balloon pump, *ICD* implantable cardioverter defibrillator, *PCI* primary coronary intervention, *ICU* intensive care unit, *LoS* length of stay

STITCH investigators concluded that no additional benefit was observed when adding SVR to CABG in patients with advanced ischemic heart disease [9]. Unfortunately, the rest of available studies are of low evidence and are mainly case series and small cohorts from high-volume centers [10–12], leaving thus the role of LV reconstruction still under debate.

Our preliminary short-term results suggest that spiral aneurysmorrhaphy can be safely performed concomitantly with TAMR for the treatment of advanced ischemic cardiac surgery. Overall mortality rate was 6.98% (0.99%

intra-operatively and 6% in-hospital post-operatively), while it did not seem to be associated with the performance of concomitant surgeries or by low pre-operative EF. Complication rate was relatively low, ranging from 0 to 5% in most cases and exceeding this range only in the case of AF, LCOS and IABP.

Even in the post-STITCH era, our results advocate that LV reconstruction still has a place in the treatment of ischemic heart disease by applying our simple technique. Current evidence profoundly supports the superiority of

Table 4 Intra- and post-operative data with respect to EF

	EF<30%			EF: 30–50%			EF>50%			p value
	n	%		n	%		n	%		
Intra-operative data										
Number of vessels bypassed, mean(SD)	3.5	1		3.2	0.7		3.4	0.5		>0.05
1	0/14	0.00%		0/35	0.00%		0/5	0.00%		
2	2/14	14.29%		4/35	11.43%		0/5	0.00%		
3	4/14	28.57%		22/35	62.86%		3/5	60.00%		
4	6/14	42.86%		8/35	22.86%		2/5	40.00%		
5	2'14	14.29%		1/35	2.86%		0/5	0.00%		
Total operative time (min), mean(SD)	238.1	41.4	180–320	228.5	51	125–335	223	30.5	180–255	>0.05
CPB time (min), mean(SD)	99.5	30.1	58–155	88.1	33.1	45–190	76	23.3	45–100	>0.05
XC time (min), mean(SD)	66.9	23.8	30–123	56.2	24.4	25–125	49.4	16.2	32–75	>0.05
PBC, mean(SD)	0.92	0.76	0–2	1.13	2.08	0–11	0.8	1.1	0–2	>0.05
FFP, mean(SD)	4.46	3.1	0–10	2.8	4.16	0–23	2.6	1.5	1–4	>0.05
PLT, mean(SD)	0	0	0	0.2	1.1	0–6	0		0	>0.05
Post-operative data										
Bleeding	1/14	7.14%		0/35	0.00%		0/5	0.00%		>0.05
MI	0/14	0.00%		1/35	2.86%		0/5	0.00%		>0.05
AF	1/14	7.14%		2/35	5.71%		0/6	0.00%		>0.05
CVA	0/14	0.00%		0/35	0.00%		0/7	0.00%		>0.05
Renal failure	0/14	0.00%		1/35	2.86%		0/8	0.00%		>0.05
Pneumonia/respiratory failure	0/14	0.00%		0/35	0.00%		0/9	0.00%		>0.05
Infection	1/14	7.14%		0/35	0.00%		0/10	0.00%		>0.05
LCOS	1/14	7.14%		1/35	2.86%		0/11	0.00%		>0.05
IABP	3/14	21.43%		0/35	0.00%		0/12	0.00%		>0.05
ICD	0/14	0.00%		0/35	0.00%		0/13	0.00%		>0.05
PCI	0/14	0.00%		0/35	0.00%		0/14	0.00%		>0.05
Re-operation	0/14	0.00%		0/35	0.00%		0/15	0.00%		>0.05
ICU	73.3	71.8	32–288	41.2	17.1	24–88	38.4	8.8	32–48	0.045
LoS	10.2	4.4	8–23	7.6	2	3–13	6.8	0.8	6–8	0.029
Intra-operative mortality	0/14	0.00%		0/35	0.00%		0/16	0.00%		>0.05
In-hospital mortality	0/14	0.00%		2/35	5.71%		0/17	0.00%		>0.05

p values refer to the comparison between EF<30%, 30–50% and EF>50% subgroups. Data expressed as absolute and relative frequencies for qualitative variables and as mean–SD range for continuous variables

EF ejection fraction, *SD* standard deviation, *CPB* cardiopulmonary bypass, *XC* cross-clamp, *PBC* packed blood cells, *FFP* fresh frozen plasma, *PLT* platelets, *MI* myocardial infarction, *AF* atrial fibrillation, *CVA* cerebrovascular accident, *LCOS* low cardiac output syndrome, *IABP* intra-aortic balloon pump, *ICD* implantable cardioverter defibrillator, *PCI* primary coronary intervention, *ICU* intensive care unit, *LoS* length of stay

TAMR over CABG with the use of venous grafts [4], as a consequence, this approach was unanimously was followed in all of our patients. Moreover, a modified technique of linear aneurysmorrhaphy was performed which provided the ability for minimization of additional operative time. It is a safe technique since it does not require resection of myocardial tissue or advanced surgical manipulations. Despite its least invasive nature, spiral aneurysmorrhaphy leads to an adequate alteration of the geometrical characteristics of the ventricular chamber which is associated with a significant decrease in the metabolic demand of the heart.

Mortality data

It is well-documented that patients undergoing LV reconstruction are high-risk patients with certain comorbidities, as such the primary outcome of interest is the early mortality [14]. Our data on early mortality are in consistency with the available literature which reports a mortality of 6.8% as proposed in the systematic review by Klein et al. [6]. The authors of the STITCH reported a 30-day mortality of 6% in the group of the patients that underwent combined SVR and CABG, which was deemed similar to that of the patients who underwent solely CABG [9]. Data from STS
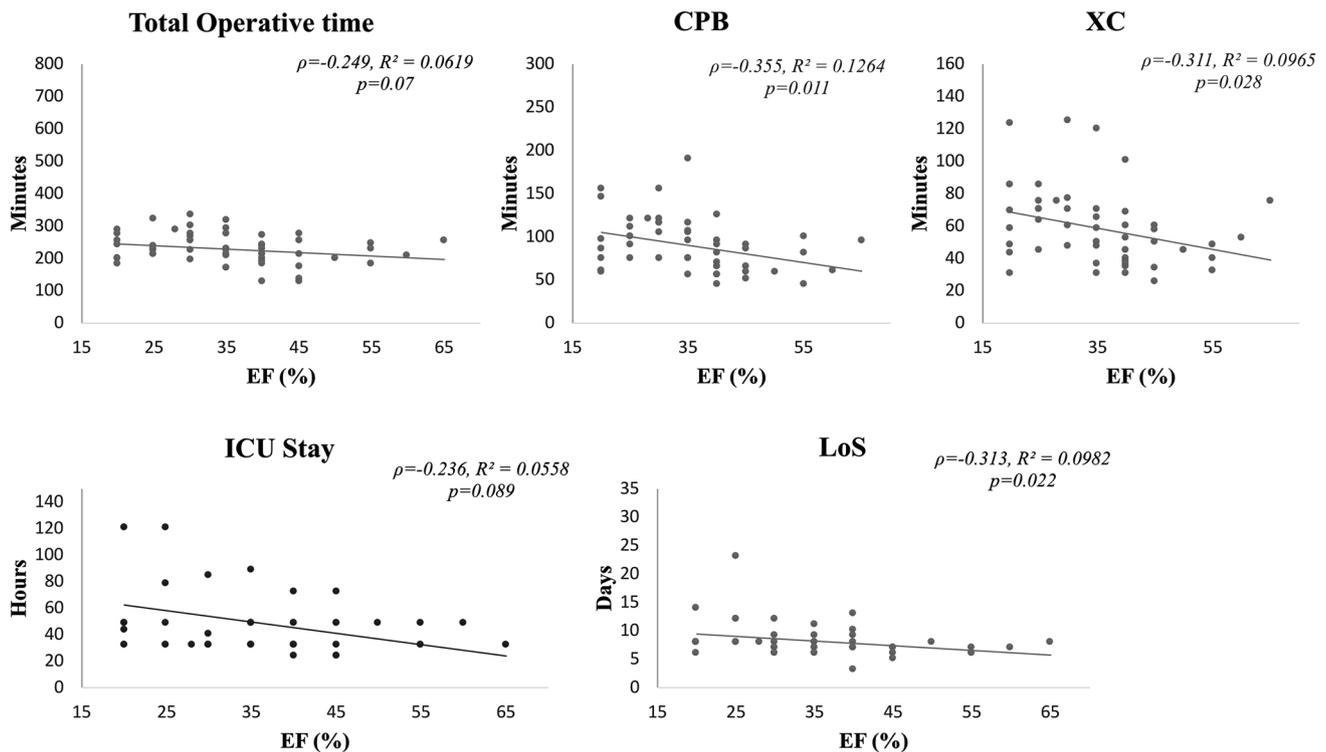
Fig. 3 Correlation between ejection fraction and **a** total operative time, **b** cardiopulmonary bypass time, **c** cross-clamp time, **d** intensive care unit stay, and **e** length of stay. Pearson's correlation coefficient has been used for analysis. Rho (ρ), R-squared and p value are indicated. *EF* ejection fraction, *CPB* cardiopulmonary bypass, *XC* Cross-clamp, *ICU* intensive care unit, *LoS* length of stay

database [15] which depicts the "real-world" application of SVR exhibit mortality rates ranging from 9 to 16% throughout the 2008–2017 period. Other tertiary referral centers for treatment of cardiovascular disease in Europe report an early mortality of 10–13% in patients undergoing LV reconstruction surgery [16–18].

Although follow-up data were not included in our study, favorable long-term outcomes are anticipated given the superiority of TAMR over the use of venous conduits in terms of patency and blood supply of the myocardium.

Post-operative complications

LCOS was the most common complication (8%) and IABP was used in 15% of the patients. Respective rates are reported by other studies [19,20], yet this number can be more than twice as high in selected groups of patients [21,22]. The rest of the complications were presented with a relatively low incidence which is in consistency with available data [11,19,23]. It is imperative to highlight that the patients included in our study had severe multi-vessel disease which required three and four grafts in approximately half and one third of the cases, respectively. Furthermore, certain pre-operative clinical variables may be correlated with specific post-operative outcomes, as such, generalization of the

comparisons between our results with distinct studies may not be legitimate. In these terms, the overall feasibility of the combined surgery should be mentioned given the overall low risk for complications.

Concomitant surgeries

Addition of concomitant surgery to CABG and SVR was associated with longer total operative time, CPB and XC time as well as increased need for PBC and FFP transfusion intra-operatively. In addition, these patients stayed longer both in ICU and in hospital. All this burden of the extra surgery was clinically manifested as an increased rate of CVA, post-operatively. This observation can be explained by the additional invasive manipulations of the myocardial tissue that are required during these concomitant surgeries. The additional surgeries that were simultaneously performed were equally divided into aortic and mitral valve surgery. Although a separate analysis of the subgroup of the patients that underwent CABG, SVR and mitral valve plasty concomitantly would be of interest given its detrimental effect on post-operative outcomes, such an attempt was not made due to the small sample size of this subgroup ($n = 5$). Yet, zero mortality was observed in this subpopulation. Mitral valve insufficiency resulted from ischemic heart disease

in all of our cases, as such surgical treatment was deemed effective even in the case of inferior aneurysms (all patients that underwent MV plasty had inferior aneurysm).

Ejection fraction

Ejection fraction was shown to be a predictor for ICU stay and LoS, especially in the subgroups of <30% and 30–50%. Moreover, a reverse correlation was observed between EF and XC and CPB time, given that low EF values are associated with a more challenging procedure. However, these associations were not translated into adverse outcomes in terms of mortality or morbidity. It is well-documented that a low EF is associated with poor outcomes such as early and late mortality [16,24]. The inconsistency of our results with the literature may be partially owed to the low incidence of complications and mortality, which could interfere with the statistical significance of our findings. Additionally, the predictive value of EF in patients with altered LV geometry should be interpreted under a specific point of view. LV end-diastolic volume is the main determinant of EF, given that stroke volume is relatively constant at rest. If the increase of the end-diastolic volume is the result of dyskinetic scar tissue, surgical restoration of the normal LV geometry will lead to enhancement of the ventricular function. In the case of increased end-systolic LV volume due to remodeling, the beneficial effects of SVR will be attenuated. Nonetheless, EF and end-systolic LV volume may provide a piece of information regarding the severity of the ventricular function impairment, however, other factors and characteristics should be also taken into consideration, so that a comprehensive overview of the "status" of the heart function and the benefit of SVR can be established. accompanied by improvement in LV function [18].

Limitations

Prior to drawing conclusions, our results should be interpreted from a certain point of view. Namely, a small sample size, lack of certain data—especially left ventricular end-systolic volume index—of the patients and the lack of follow-up add up to the limitations of the study. However, the homogeneity of the included patients' characteristics and the fact that all of the operations were performed by the same surgeon enhance the reliability of our outcomes.

Spiral aneurysmatorrhapy can be safely performed during TAMR in patients with small LV aneurysms due to ischemic cardiac disease. Early mortality is within the acceptable range according to the currently available data reporting 30-day mortality rates around 7%. Major comorbidities, namely LCOS (8%) and the need for IABP (15%) are also comparable with the ones stated in the bibliography (approximately 9% and 19%, respectively) [2,9–12]. Our results also advocate that early mortality and post-operative comorbidities are not associated with pre-operative EF or the performance of concomitant surgeries, except for higher post-operative CVA rates when an additional surgery is simultaneously performed. The enhanced results on the LV geometry along with the optimal reperfusion of the myocardium provided by the arterial conduits may be the ideal "surgical package" for these patients. Follow-up of these patients is pending to validate the long-term efficacy of this combined operation.

Compliance with ethical standards

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