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Systematic Review

Surgical ventricular reconstruction for ischemic cardiomyopathy—a systematic review and meta-analysis of 7,685 patients

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Background: Surgical ventricular reconstruction (SVR) has been used to control adverse ventricular remodeling and improve cardiac function in ischemic cardiomyopathy. The purpose of this systematic review and meta-analysis was to collect and analyze all available evidence on the utilization and efficacy of SVR.

Methods: An electronic database search was performed to identify all retrospective and prospective studies on SVR for ischemic cardiomyopathy in the English literature from 2000 through 2020. A total of 92 articles with a collective 7,685 patients undergoing SVR were included in the final analysis.

Results: The mean patient age was 61 years (95% CI: 59–63) and 80% (78–82%) were male. Congestive heart failure was present in 66% (54–78%) and angina in 58% (45–70%). Concomitant coronary artery bypass grafting was undertaken in 92% (90–93%) while 21% (18–24%) underwent mitral valve repair. Pre *vs.* post-SVR, significant improvement was seen in left ventricular ejection fraction (LVEF) [29.9% (28.8–31.2%) *vs.* 40.9% (39.4–42.4%), P<0.01], left ventricular end-systolic (LVESD) and end-diastolic diameters (LVEDD) [LVESD: 49.9 mm (48.1–51.7) *vs.* 45 mm (42.8–47.3), P<0.01, LVEDD: 63.8 mm (62–65.6) *vs.* 58.23 mm (56.6–60), P<0.01], and left ventricular end-systolic (LVESVI) and end-diastolic volume indices (LVEDVI) [LVESVI: 83.9 mL/m^2 (79.3–88.4) *vs.* 46.8 mL/m^2 (43.5–50.1), P<0.01; LVEDVI: 119.9 mL/m^2 (112.1–127.6) *vs.* 79.6 mL/m^2 (73.6–85.7), P<0.01]. Mean New York Heart Association class improved from 3 (2.8–3.1) to 1.8 (1.5–2) (P<0.01). The 30-day mortality was 4% (3–5%) while late mortality was 19% (9–34%) at a mean follow-up of 27.5 [21–34] months.

Conclusions: In patients with ischemic cardiomyopathy, SVR reduces left ventricular volumes and improves systolic function leading to symptomatic improvement.

Keywords: Surgical ventricular reconstruction (SVR); ventricular restoration; dor procedure; ventricular aneurysm repair; endoventricular plasty

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Introduction

With an ever-increasing disease burden, coronary artery disease is the foremost cause of heart failure and myocardial infarction (1). Acute myocardial infarction (AMI) leads to a number of acute and chronic complications that are mediated by various factors. Post-AMI sequelae are characterized by myocardial remodeling—an umbrella term for repair of necrotic heart muscle through thinning, formation of collagen scars, compensatory hypertrophy of non-infarcted myocardium, and eventual ventricular dilation with change in its geometry (2,3). The mechanism underlying remodeling is change at a molecular and cellular level which occurs in response to myocardial necrosis post-AMI. Maladaptive remodeling further negatively affects ventricular function and eventually leads to congestive heart failure, the incidence of which is increasing in survivors of acute MI. Current therapies are targeted at preventing and reversing such adverse remodeling (1-3).

Surgical ventricular reconstruction (SVR) is an attempt at controlling adverse ventricular remodeling by excluding dyskinetic and scarred ventricle, prevention of further ventricular dilation, and restoration of the geometry of the ventricle (2). This procedure, with its subsequent modifications, was pioneered by Cooley (4), Dor (5) and Jatene (6). However, the Dor procedure/modification is the most widely used technique of SVR, which is otherwise called endoventricular patch plasty (EVCPP) (7). The aim is to reduce LV volume and restore the elliptical shape of the ventricle thereby improving EF as well as cardiac function. This surgery is usually undertaken concurrently with coronary artery bypass graft (CABG) surgery.

In 2009, results of the Surgical Treatment for Ischemic Heart Failure (STICH) trial (8) reported greater reduction in ventricular volume with addition of SVR to CABG but no difference in rates of death or hospitalization due to cardiac causes. These results put into question the utility of SVR when combined with CABG and led to a decrease in its popularity (2,9). Being the most consequential trial on SVR efficacy in the last few decades, the STICH trial started conversations regarding the proper place of SVR in treatment of post-MI remodeling and heart failure.

Given the discordant views and results regarding the efficacy of SVR, we sought to gather and analyze in granular detail, all available evidence on the utilization of SVR in patients suffering from ischemic cardiomyopathy. Through this systematic review and meta-analysis, we hope to evaluate the efficacy and utility of SVR.

Methods

Literature search strategy

An electronic database search was performed in June 2020 using MEDLINE (Ovid SP), Scopus, Cochrane Controlled Trials Register (CCTR) and Cumulative Index to Nursing and Allied Health Literature (CINAHL). To achieve maximum sensitivity, the following terms were combined: “Dor procedure”, “modified Dor”, “endoventricular circular patch plasty”, “endoventricular plasty”, “Endoventricular patch plasty”, “endocardial patch”, “ventricular reconstruction”, “ventricular restoration”, “Surgical ventricular restoration”, “ventricular infarct exclusion”, “ventricular aneurysmectomy”, “Ventricular aneurysm repair”, “ventricular endocardial restoration” and “Ventriculoplasty” as either key words or MeSH terms. The references of included studies were manually searched (BF, GG) and did not yield additional studies for inclusion.

Eligibility criteria

Eligible articles for this systematic review were full-length studies published from January 2000 to May 2020 in the English literature that included adults undergoing left ventricular reconstruction for ischemic cardiomyopathy. All technical approaches for SVR were included. Studies that included patients not undergoing left ventricular reconstruction or included patients with non-ischemic cardiomyopathy were excluded. Case reports, abstracts, conference presentations, editorials, reviews and expert opinions were also excluded. When institutions published more than one study including overlapping patient populations, only the most complete reports were included. The Newcastle-Ottawa Scale (NOS) scoring system was utilized to assess risk of bias for the identified studies as recommended by the Cochrane Collaboration.

Data extraction and critical appraisal

Study level data were extracted from the text, figures and tables of all eligible articles (BF, KM, GG). Discrepancies between the reviewers were resolved by discussion and consensus.

Statistical analysis

Baseline patient characteristics and clinical outcomes were reported as the pooled mean with 95% confidence intervals (CI). For dichotomous variables, a meta-analysis of proportions with logit transformation was conducted for preoperative and postoperative variables. Continuous data were combined via meta-analysis with random-effects model. Heterogeneity was evaluated using Cochran Q and I^2 test. Survival data from each study were collected and pooled to retrieve a weighted mean and 95% confidence interval at specific time points. Such data were then graphically displayed to visualize survival over time. R software 3.5.0, meta package (R Foundation for Statistical Computing, Vienna, Austria) was used for data analysis. P values <0.05 were considered statistically significant.

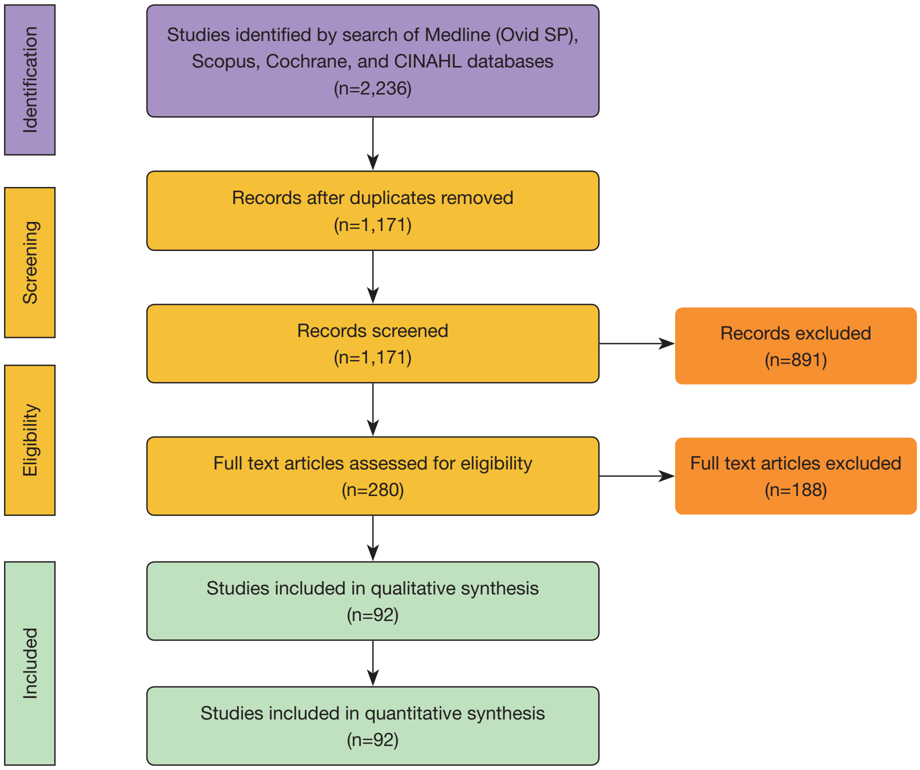

Figure 1 PRISMA schematic diagram of the search strategy. PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analysis.

Results

Study characteristics

A total of 2,236 articles were identified by conducting the search of four databases. Eligible studies included all prospective and retrospective studies on patients who underwent SVR for ischemic cardiomyopathy. After removal of duplicate articles, 1,171 articles remained. A total of 891 articles were excluded after a detailed evaluation of the title and abstract of each article. The remaining 280 articles underwent a full text evaluation, of which ninety-two articles met inclusion criteria with a collective 7,685 patients. The mean NOS score for included studies was six. Sixty studies had a score of either six or seven, indicating that a majority of the included studies were of fair to good quality. A PRISMA flow diagram illustrating the search strategy is provided in *Figure 1*. A detailed list of the studies included is located in the supplementary material as Table S1. In addition, NOS scoring details for all included studies are presented in the supplementary material as Table S2.

Baseline characteristics

The mean age of patients was 61 years (95% CI: 59–63) with 80% (78–82%) being male. Common comorbidities included hypertension [56% (52–61%)], hyperlipidemia [52% (45–58%)], and diabetes [30% (27–32%)]. Congestive heart failure was present in 66% (54–78%) while angina was seen in 58% (45–70%) of patients at time of presentation. Akinesis of ventricular wall segments was seen in 46% (31–61%) while 54% (36–71%) of patients presented with dyskinesis. Average time from previous myocardial infarction to surgery was 18.2 months (9.4–27.0) and 25% (18–33%) of patients had undergone previous percutaneous coronary intervention (PCI). The mean number of coronary vessels involved was 2.5 (2–3). Left anterior descending disease was most frequently seen [93% (88–97%)] followed by right coronary [58% (37–80%)], and left circumflex [45% (11–79%)] disease respectively. Further baseline characteristics are shown in *Table 1*.

Table 1 Baseline characteristics

Characteristics	Pooled value [95% CI]	No. of studies	No. of patients (N or n/N)	I^2 (%)
Age (years)	61.1 [59.4, 62.8]	72	6,268	100
Male (%)	80 [78, 82]	78	5,254/6,647	81*
BMI (kg/m^2)	25.7 [23.4, 27.9]	7	1,000	0
BSA (m^2)	1.7 [1.6, 1.8]	7	232	0
Hypertension (%)	56 [52, 61]	40	2,092/3,957	86*
Hyperlipidemia (%)	52 [45, 58]	22	1,083/2,122	88*
Pulmonary hypertension (%)	23 [13, 32]	5	85/366	84*
Angina (%)	58 [45, 70]	25	1,539/3,038	99*
Unstable angina (%)	34 [21, 48]	5	104/353	88*
Cerebrovascular disease (%)	12 [8, 15]	7	77/595	46
Chronic lung disease (%)	17 [12, 22]	13	186/998	87*
Smoker, previous or current (%)	58 [52, 64]	22	1,288/2,160	90*
Diabetes (%)	30 [27, 32]	54	1,450/4,995	78*
Atrial fibrillation (%)	14 [10, 18]	11	214/1,750	87*
Ventricular tachycardia (%)	22 [13, 30]	10	263/994	94*
Congestive heart failure (%)	66 [54, 78]	12	848/1,258	99*
Renal dysfunction (%)	10 [6, 14]	17	232/1,443	90*
Peripheral vascular disease (%)	10 [8, 11]	14	124/1,150	11
Previous heart surgery (%)	6 [3, 9]	12	80/865	79*
Previous ICD implant (%)	12 [7, 18]	5	90/575	72*
Previous PCI (%)	25 [18, 33]	13	324/1,212	90*
Previous MI (%)	100 [99, 100]	65	5,509/5,637	63*
Previous MI, anterior (%)	99 [98, 100]	16	1,225/1,274	73*
Previous MI, posterior or inferior (%)	16 [8, 24]	6	60/330	82*
Previous MI, anteroseptal (%)	87 [79, 94]	6	509/602	99*
Time from previous MI to surgery (months)	18.2 [9.4, 27.0]	7	1,915	65*
Aneurysm location				
Anterior (%)	92 [89, 95]	20	1,558/1,741	84*
Anteroseptal (%)	77 [70, 84]	4	398/468	98*
Apico-anterior (%)	89 [81, 97]	4	332/379	89*
Inferior (%)	5 [2, 9]	4	22/316	44
Posterior (%)	18 [7, 28]	10	125/1,122	98*
Thrombus in left ventricle (%)	38 [26, 51]	12	341/921	95*

Table 1 (*continued*)

Table 1 (*continued*)

Characteristics	Pooled value [95% CI]	No. of studies	No. of patients (N or n/N)	I^2 (%)
Coronary vessel disease, No. of vessels (mean)	2.5 [2.0, 3.1]	6	357	0
Single vessel disease (%)	14 [11, 18]	29	547/3,020	89*
Double vessel disease (%)	23 [19, 26]	28	732/2,878	79*
Triple vessel disease (%)	60 [54, 66]	33	1,828/3,346	93*
Left main disease (%)	10 [8, 13]	22	250/2,151	66*
Left anterior descending artery disease (%)	93 [88, 97]	10	698/780	89*
Left circumflex artery disease (%)	45 [11, 79]	4	73/159	97*
Right coronary artery disease (%)	58 [37, 80]	4	86/132	87*
LV akinesis (%)	46 [31, 61]	10	476/1,178	97*
LV dyskinesis (%)	54 [36, 71]	10	674/1,294	98*

*, heterogeneity P<0.05 (significant data heterogeneity present). BMI, body mass index; BSA, body surface area; ICD, implantable cardioverter defibrillator; PCI, percutaneous coronary intervention; MI, myocardial Infarction; LV, left ventricle.

Pre-operative characteristics

At time of surgery, mean LVEF was 30.0% (28.8–31.2%) with a LVEDVI of 119.9 (112.1–127.6) mL/m^2 and a LVESVI of 88.2 (81.6–94.8) mL/m^2 respectively. Mean MR grade was 1.8 (1.4–2.1) with an associated New York Heart Association (NYHA) class of 3.0 (2.8–3.1). 32% (21–42%) of patients were on inotropic support and 15% (4–25%) required an intra-aortic balloon pump (IABP). Additional pre-operative characteristics are included in *Table 2*.

Operative characteristics

The mean cardiopulmonary bypass time was 128 minutes (117–140 minutes) and the aortic cross-clamp time was 84.5 minutes (76–93 minutes). Concurrent with SVR, 92% (90–93%) of patients underwent CABG with an average of 2.6 grafts [2.3–2.9]. Other concomitant procedures included cryoablation [26% (17–35%)], mitral valve repair [21% (18–24%)] and tricuspid valve repair/replacement [14% (10–19%)]. Utilization of a ventricular patch [67% (58–76%)] was preferred to performing SVR without a patch [33% (24–42%)]. Further intraoperative details are presented in *Table 3*.

Pre *vs.* post-operative comparison

There was a significant increase in LVEF after SVR [pre-operative, 30.0% (28.8–31.2%) *vs.* post-operative, 40.9% (39.4–42.4%), P<0.01] along with decrease in NYHA class [pre-operative, 3.0 (2.8–3.1) *vs.* post-operative, 1.8 (1.5–2.0), P<0.01]. There were significant decreases after SVR in LVESVI [pre-operative, 83.9 (79.3–88.4) mL/m^2 *vs.* post-operative, 46.8 (43.5–50.1) mL/m^2, P<0.01] and LVEDVI [pre-operative, 111.9 (112.1–127.6) mL/m^2 *vs.* post-operative, 79.6 (73.6–85.7) mL/m^2, P<0.01]. The incidence of pulmonary hypertension trended down from 23% (14–37%) preoperatively to 15% (5–40%) postoperatively (P=0.34). Pulmonary capillary wedge pressure (PCWP) was comparable pre *vs.* post-SVR [13.6 (10.1–17.1) mmHg *vs.* 10.9 (7.5–14.2) mmHg, P=0.27]. Further post-operative details are presented in *Table 4*, and pre- to post-operative comparisons are included in *Table 5*.

Survival and outcomes

Mean total hospital length of stay was twelve days (10–15) while ICU length of stay was four days (3.3–5.5). The 30-day mortality was 4% (3–5%) while late mortality was 19% (9–34%) at a mean follow-up of 27.5 [21–34] months. There was no difference in total mortality between the Dor [12% (8–17%)] and linear techniques [20% (7–44%)] (P=0.16). *Figure 2* shows cumulative survival up to 15 years post SVR. The most frequent postoperative complications included atrial fibrillation [23% (17–29%)], low cardiac output [13% (9–17%)] and infection [11% (5–18%)]. The most frequent causes of death were heart failure [7% (5–10%)], arrhythmia [3% (1–4%)] and sepsis [3% (1–5%)]. Seven percent (3–11%) of patients required subsequent placement of a pacemaker and 2% (0–5%) required a left ventricular

Table 2 Pre-operative characteristics

Characteristics	Pooled value [95% CI]	No. of studies	No. of patients (N or n/N)	I^2 (%)
EF (%)	30.0 [28.8, 31.2]	82	6,925	0
Cardiac Index (L/min/m^2)	2.4 [2.2, 2.6]	10	583	0
Stroke volume index (mL/m^2)	30.1 [23.0, 38.9]	3	168	0
LVEDVI (mL/m^2)	119.9 [112.1, 127.6]	45	3,325	15
LVESVI (mL/m^2)	88.2 [81.6, 94.8]	37	3,723	62*
LVEDV (mL)	200.8 [174.6, 227.0]	16	1,095	55*
LVESV (mL)	128.9 [105.3, 152.5]	16	1,076	71*
LVEDD (mm)	63.8 [62.0, 65.6]	36	3,267	0
LVESD (mm)	49.9 [48.1, 51.7]	29	2,275	0
Diastolic eccentricity index	0.8 [0.7, 0.8]	6	541	0
Systolic eccentricity index	0.8 [0.8, 0.9]	4	434	0
Diastolic sphericity index	0.6 [0.6, 0.7]	6	1,171	60*
Systolic Sphericity index	0.6 [0.6, 0.7]	4	717	0
E/A (cm/s)	2.7 [0.5, 4.8]	7	738	93*
E/E' (cm/s)	18.7 [11.0, 26.3]	4	199	0
Decel time (ms)	161.7 [135.9, 187.6]	6	320	0
Pulmonary artery pressure (mmHg)	29.9 [25.3, 32.6]	16	1,678	0
Pulmonary capillary wedge pressure (mmHg)	13.6 [10.1, 17.1]	7	467	0
MR Grade (mean)	1.8 [1.4, 2.1]	17	1127	39*
MR Grade 0 (%)	27 [18, 37]	13	339/1,321	97*
MR Grade 1 (%)	32 [24, 39]	18	486/1,724	96*
MR Grade 2 (%)	22 [16, 27]	17	364/1,582	90*
MR Grade 3 (%)	11 [6, 15]	15	287/1,813	92*
MR Grade 4 (%)	6 [4, 8]	17	154/1,634	87*
NYHA Class (mean)	3.0 [2.8, 3.1]	34	2,092	0
NYHA Class I (%)	1 [0, 2]	34	87/2,656	57*
NYHA Class II (%)	22 [18, 27]	35	655/2,757	96*
NYHA Class III (%)	51 [45, 56]	40	1,676/3,347	90*
NYHA Class IV (%)	22 [17, 26]	42	813/3,436	94*
Inotropic support (%)	32 [21, 42]	8	150/403	83*
IABP (%)	15 [4, 25]	15	106/822	97*
Urgent/emergent procedure (%)	13 [9, 16]	23	1,684	85*

*, heterogeneity P<0.05 (significant data heterogeneity present). LVEDVI, left ventricle end-diastolic volume index; LVESVI, left ventricle end-systolic volume index; LVEDV, left ventricle end-diastolic volume; LVESV, left ventricle end-systolic volume; LVEDD, left ventricle end-diastolic diameter; LVESD, left ventricle end-systolic diameter; MR, mitral regurgitation; NYHA, New York Heart Association; IABP, intra-aortic balloon pump.

Table 3 Operative characteristics

	Pooled value [95% CI]	No. of studies	No. of patients (N or n/N)	I^2 (%)
CPB (%)	99 [98, 100]	71	5,272/5,318	98*
CPB time (minutes)	128.2 [116.6, 139.8]	42	3,487	68*
Aortic cross clamp (%)	91 [86, 97]	43	2,910/3,225	100*
Aortic cross clamp time (minutes)	84.5 [76.0, 93.0]	37	3,014	28*
Cardioplegia (%)	86 [81, 91]	56	3,368/3,838	100*
SVR technical approach				
Patch (%)	67 [58, 76]	84	3,737/6,885	100*
Dor/circular patch (%)	95 [91, 97]	45	2,552/3,522	92*
Patchless (%)	33 [24, 42]	84	3,139/6,885	100*
Linear (%)	81 [78, 85]	23	1,817/2,268	98*
Balloon mannequin utilized (%)	92 [72, 100]	16	1,328/1,633	100*
Concomitant procedure				
CABG (%)	92 [90, 93]	82	5,950/6,817	91*
No. of grafts (mean)	2.6 [2.3, 2.9]	45	3,764	0
No. of grafts: 1 (%)	19 [12, 25]	10	119/543	74*
No. of grafts: 2 (%)	24 [15, 33]	8	85/311	70*
No. of grafts: 3 (%)	28 [17, 40]	8	107/311	81*
No. of grafts: >3 (%)	18 [10, 26]	6	43/226	58*
Internal mammary artery harvested (%)	67 [57, 76]	27	1,847/2,868	99*
LAD revascularized (%)	84 [79, 90]	11	951/1,123	87*
Aortic valve replacement or repair (%)	2 [1, 4]	11	37/1,282	33
Mitral valve repair (%)	21 [18, 24]	70	1,046/5,426	99*
Mitral valve replacement (%)	1 [0, 1]	43	73/3,429	19
Tricuspid valve replacement / repair (%)	14 [10, 19]	14	186/1,386	91*
Cryoablation (%)	26 [17, 35]	13	419/1,440	96*
Ventricular septal defect closure (%)	3 [2, 5]	7	31/737	23

*, heterogeneity P<0.05 (significant data heterogeneity present). CPB, cardiopulmonary bypass; SVR, surgical ventricular reconstruction; CABG, coronary artery bypass graft; LAD, left anterior descending.

assist device (LVAD). Further outcomes and complications are described in *Table 6*.

Discussion

Utilization of SVR has been greatly impacted by the STICH trial. Critics have pointed out flaws in its methodology and interpretation of results (2,10,11), while others have argued against broad application of SVR in ischemic cardiomyopathy (12). This has led to the notion that SVR should be used cautiously in carefully selected patients, which is best reflected in the European Association for Cardio–Thoracic Surgery (EACTS) and European Society of Cardiology (ESC) guidelines on myocardial revascularization in chronic heart failure. Considering SVR with CABG in patients with coronary artery disease, a scarred ventricle and LVESVI >60 mL/m^2 is a class IIb recommendation in these guidelines (13).

Table 4 Post-operative characteristics

	Pooled value [95% CI]	No. of studies	No. of patients (N or n/N)	I^2 (%)
Latest follow-up EF (%)	40.9 [39.4, 42.4]	63	5,310	0
EF, 3 month (%)	39.0 [34.9, 43.1]	4	250	0
EF, 1 year (%)	41.1 [35.0, 47.3]	6	408	0
EF, 2 year (%)	37.8 [32.3, 43.4]	5	395	0
Cardiac index (L/min/m^2)	2.8 [2.5, 3.2]	6	373	0
SVI (mL/m^2)	29.2 [18.1, 40.2]	5	222	34
LVEDVI (mL/m^2)	79.6 [73.6, 85.7]	35	2,363	14
LVESVI (mL/m^2)	46.8 [43.5, 50.1]	40	2,747	0
LVEDV (mL)	140.1 [121.1, 159.1]	18	1,596	59*
LVESV (mL)	72.2 [60.5, 83.9]	17	1,438	40*
LVEDD (mm)	58.3 [56.6, 60.0]	30	2,884	0
LVESD (mm)	45.0 [42.8, 47.3]	22	1,897	0
Diastolic eccentricity index	0.7 [0.7, 0.8]	6	541	29
Systolic eccentricity index	0.8 [0.7, 0.9]	4	434	0
Diastolic sphericity index	0.6 [0.5, 0.7]	5	1,028	70*
Systolic sphericity index	0.6 [0.6, 0.7]	3	574	28
E/A (cm/s)	1.7 [0.9, 2.4]	5	576	43
E/E' (cm/s)	21.2 [14.0, 28.4]	3	180	0
Pulmonary artery pressure, mean (mmHg)	25.6 [22.2, 29.0]	8	542	0
Pulmonary capillary wedge pressure (mmHg)	10.9 [7.5, 14.2]	6	352	0
Pulmonary hypertension (%)	15 [5, 25]	3	34/208	82*
MR Grade (mean)	0.9 [0.7, 1.1]	14	1,028	0
MR Grade 0 (%)	43 [29, 57]	7	532/1,070	88*
MR Grade 1 (%)	22 [12, 38]	8	206/1,114	92*
MR Grade 2 (%)	14 [8, 24]	7	229/1,025	86*
MR Grade 3 (%)	6 [3, 10]	5	19/393	0
MR grade 4 (%)	3 [2, 5]	5	15/455	0
NYHA Class (mean)	1.8 [1.5, 2.0]	21	1,181	0
NYHA Class I (%)	49 [36, 62]	23	798/1,916	98*
NYHA Class II (%)	31 [23, 39]	22	499/1,632	93*
NYHA Class III (%)	6 [4, 8]	20	99/1,306	71*
NYHA Class IV (%)	1 [0, 2]	19	28/1,254	6

*, heterogeneity P<0.05 (significant data heterogeneity present). EF, ejection fraction; SVI, systolic volume index; LVEDVI, left ventricle end-diastolic volume index; LVESVI, left ventricle end-systolic volume index; LVEDV, left ventricle end-diastolic volume; LVESV, left ventricle end-systolic volume; LVEDD, left ventricle end-diastolic diameter; LVESD, left ventricle end-systolic diameter; MR, mitral regurgitation; NYHA, New York Heart Association.

Table 5 Pre- versus post-operative characteristics

Characteristics	Pre-operative				Post-operative				P value
	No. of studies	No. of patients	Pooled value [95% CI]	I^2	No. of studies	No. of patients	Pooled value [95% CI]	I^2	
EF (%)	82	6,925	30.0 [28.8, 31.2]	0	63	5,310	40.9 [39.4, 42.4]	0	<0.01
Cardiac index (L/min/m^2)	10	583	2.4 [2.2, 2.6]	0	6	373	2.8 [2.5, 3.2]	0	0.04
LVEDVI (mL/m^2)	45	3,325	119.9 [112.1, 127.6]	15	35	2,363	79.6 [73.6, 85.7]	14	<0.01
LVESVI (mL/m^2)	51	3,723	83.9 [79.3, 88.4]	0	40	2,747	46.8 [43.5, 50.1]	0	<0.01
LVEDD (mm)	36	3,267	63.8 [62.0, 65.6]	0	30	2,884	58.3 [56.6, 60.0]	0	<0.01
LVESD (mm)	29	2,275	49.9 [48.1, 51.7]	0	22	1,897	45.0 [42.8, 47.3]	0	<0.01
PAP (mmHg)	16	1,678	29.0 [25.3, 32.6]	0	8	542	25.6 [22.2, 29.0]	0	0.18
PCWP (mmHg)	7	467	13.6 [10.1, 17.1]	0	6	352	10.9 [7.5, 14.2]	0	0.27
Pulmonary hypertension (%)	5	85/366	23 [13, 32]	84*	3	34/208	15 [5, 25]	82*	0.34
MR grade (mean)	17	1,127	1.6 [1.3, 1.8]	16	14	1,028	0.9 [0.7, 1.1]	0	<0.01
NYHA class (mean)	34	2,092	3.0 [2.8, 3.1]	0	21	1,181	1.8 [1.5, 2.0]	0	<0.01

*, heterogeneity P<0.05 (significant data heterogeneity present). EF, Ejection fraction; LVEDVI, left ventricle end-diastolic volume index; LVESVI, left ventricle end-systolic volume index; LVEDD, left ventricle end-diastolic diameter; LVESD, left ventricle end-systolic diameter; PAP, pulmonary artery pressure; PCWP, pulmonary capillary wedge pressure; MR, mitral regurgitation; NYHA, New York Heart Association.

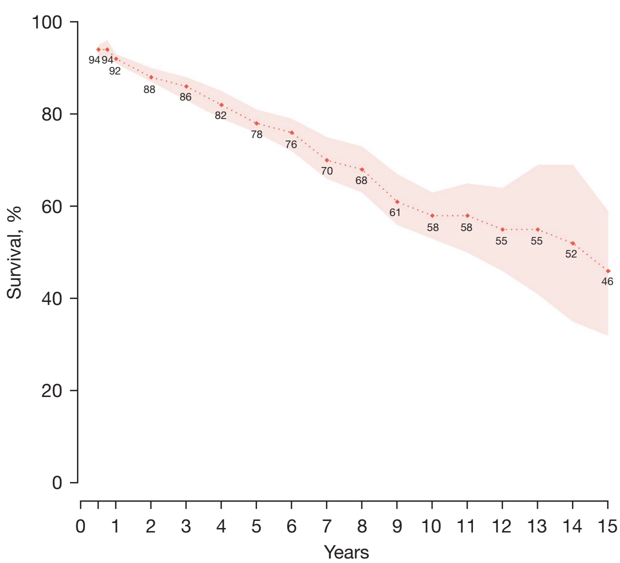

Figure 2 Pooled survival over time after surgical ventricular reconstruction (SVR). Central line represents pooled mean while shaded region represents 95% confidence intervals.

Of note, the STICH trial was not included in our systematic review/meta-analysis to avoid overlap and double entry of data from its participating institutions. It is worth mentioning that the STICH trial included 501 patients who underwent CABG + SVR (8), while our analysis is based on pooled data from 7,685 patients who all underwent SVR with 92% undergoing concomitant CABG.

The main criticism of STICH is related to patient selection/inclusion and procedural issues. An average reduction of 19% in LVESVI was reported in the CABG + SVR group (8), which is lower than the benchmark of at least a 30% reduction usually achieved by SVR (11). This could have affected the results because postoperative LVESVI is associated with survival. Patients with a postoperative LVESVI greater than 60 mL/m^2 have poorer survival than those with an LVESVI <60 mL/m^2 (14). Our analysis shows a reduction in LVESVI from 83.9 mL/m^2 preoperatively to 46.8 mL/m^2 postoperatively—a decrease of 44% and below the 60 mL/m^2 threshold for survival benefit.

Table 6 Surgical ventricular reconstruction outcomes and complications

	Pooled value [95% CI]	No. of studies	No. of patients (N or n/N)	I^2 (%)
Hospital admission				
Prolonged ventilation (%)	9 [4, 14]	6	34/341	65*
Time on ventilator (hours)	27.0 [20.9, 33.1]	6	369	0
Placement of IABP intra- or post-operative (%)	20 [16, 24]	50	864/4,611	95*
Inotropic support required (%)	43 [33, 53]	14	766/1,663	95*
Inotropic support duration (hours)	44.2 [22.0, 66.5]	3	175	0
Hospital length of stay (days)	12.4 [9.8, 15.0]	13	821	18
ICU length of stay (days)	4.4 [3.3, 5.5]	13	974	0
Total follow up (months)	27.5 [21.0, 34.0]	24	2,201	59*
Mortality				
Operative mortality (%)	4 [3, 5]	74	344/6,414	48*
Late mortality (%)	19 [9, 34]	8	122/577	80*
Mortality, Linear (%)	20 [7, 44]	5	118/464	82*
Mortality, Dor (%)	12 [8, 17]	10	42/399	20
Subsequent procedure				
Placement of defibrillator (%)	5 [3, 8]	9	67/1,080	65*
Placement of pacemaker (%)	7 [3, 11]	3	48/873	77*
Placement of LVAD (%)	2 [0, 5]	4	17/714	72*
Heart transplantation (%)	2 [1, 3]	4	24/981	0
Complication				
Angina (%)	5 [2, 9]	3	5/108	0
Myocardial infarction (%)	4 [2, 6]	7	27/840	22
Low cardiac output (%)	13 [9, 17]	13	119/862	80*
Atrial fibrillation (%)	23 [17, 29]	9	294/1,170	81*
Ventricular tachycardia (%)	6 [2, 9]	6	39/738	76*
Bleeding (%)	3 [1, 5]	4	13/325	10
Respiratory failure (%)	9 [5, 13]	6	49/506	55*
Cerebrovascular accident (%)	1 [1, 3]	19	48/2,539	19
Infection, unspecified (%)	11 [5, 18]	5	64/498	81*
Wound Infection (%)	3 [0, 7]	3	7/168	64
Pneumonia (%)	6 [3, 11]	4	18/329	0
Mediastinitis (%)	1 [0, 3]	5	5/283	0
Sepsis (%)	3 [1, 6]	3	9/228	0
Renal insufficiency (%)	5 [3, 7]	19	140/1,888	75*
Dialysis (%)	3 [1, 6]	4	15/747	49

Table 6 (*continued*)

Table 6 (*continued*)

	Pooled value [95% CI]	No. of studies	No. of patients (N or n/N)	I^2 (%)
Cause of death				
Arrhythmia (%)	3 [1, 4]	14	48/1,118	62*
Heart failure (%)	7 [5, 10]	15	108/1,453	49*
Cerebrovascular (%)	2 [2, 4]	12	25/1,328	0
Multi-organ failure (%)	2 [1, 3]	6	11/407	0
Pneumonia (%)	2 [0, 4]	7	11/300	0
Cancer (%)	1 [1, 2]	12	28/1,111	6
Sepsis (%)	3 [1, 5]	5	7/194	0
Sudden death (%)	3 [2, 4]	6	25/755	0*
Unknown (%)	3 [1, 7]	5	12/569	43

*, heterogeneity P<0.05 (significant data heterogeneity present). IABP, intra-aortic balloon pump; ICU, intensive care unit.

Our results are comparable to the 30% to 50% pre- to post-operative reduction reported in the literature (10,11). This decrease in LVESVI, together with a reduction in the radius of the ventricle, decreases myocardial wall stress according to Laplace's law. This is a potent means of inducing reverse remodeling (14,15).

Our results show an increase of mean LVEF from 30.0% preoperatively to 40.9% postoperatively. This is comparable to a series reported by Dor *et al.* where LVEF increased from 26% to 44% one year after SVR (10). In contrast, LVEF of STICH patients undergoing CABG plus SVR increased from 21% to 27% only (8). Variation in technique could account for this difference because more than half of these patients had an LVESVI >60 mL/m^2 after surgery (8). After SVR, a mean increase of 10 to 15 points in LVEF has been previously reported (16). This improvement in LVEF is due to the decrease in wall tension and improved contractility resulting from scar removal and restoration of the elliptical shape of the left ventricle (17).

One potential drawback previously reported by Dor is the late worsening of pulmonary hypertension after SVR, which was thought to be due to reduced compliance of the left ventricle by surgical reshaping (7,16). In our analysis, the incidence of pulmonary hypertension trended down from 23% (14–37%) preoperatively to 15% (5–40%) postoperatively (P=0.34). Though this data was limited by the small number of articles with such information reported, the improvement is likely due to an improvement in systolic and diastolic function which subsequently reduces pulmonary pressure. As a result, a reduction in congestive heart failure symptoms is expected, which our results support with an improvement in NYHA functional classification score after SVR. Similar results are also reported by Patel *et al.* (18).

In our analysis, 21% had concomitant mitral valve repair and 1% had mitral valve replacement. The degree of MR significantly decreased pre to post-operatively (1.6 *vs.* 0.9) (P<0.01). The Reconstructive Endoventricular Surgery, returning Torsion Original Radius Elliptical Shape to the LV (RESTORE) group has reported similar outcomes, with 23% of their population undergoing mitral valve intervention (22% repair, 1% replacement) (19).

We report an operative mortality of 4% in this meta-analysis. Survival at 1, 5, 10 and 15 years was 92%, 78%, 58%, and 46% respectively. In a recent series, Dor described a 5-year survival of 88% and 79% survival at 100 months post-SVR (10). Isomura *et al.* from the RESTORE group reported an 8-year survival of 82.4% in patients with postoperative LVESVI <90 mL/m^2 while patients with postoperative LVESVI >90 mL/m^2 had 0% survival at eight years (19). In the present review, eight-year survival was 68% with an LVESVI of 46.8 mL/m^2 postoperatively. Our lower reported survival at eight years is likely due to the inclusion of patients with postoperative LVESVI >90 mL/m^2 in included studies. Nonetheless, our results support several other studies, mentioned previously, suggesting the survival benefit of SVR.

Limitations

A large number of retrospective studies are included in the analysis. Due to their risk of bias, much of the data is considered moderate quality in our GRADE assessment. However, this represents the largest dataset of SVR patients to have been analyzed. We were unable to complete a quantitative comparison for CABG *vs.* CABG + SVR since most studies did not have comparative arms for statistical analysis; therefore, we were unable to report survival benefit. Additional future analysis exploring mitral valve intervention in SVR would be beneficial. We also acknowledge the differences in patient selection and surgical technique of SVR, however it was a fundamental limitation that cannot be addressed when working with pooled data.

Conclusions

Surgical ventricular reconstruction reduces left ventricular volume and improves systolic function in patients with ischemic cardiomyopathy. Our results suggest long term survival comparable to existing reports and good symptomatic improvement following intervention. Further research is still needed to explore the optimal indications of SVR and to identify the group of patients who benefit the most from it.

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Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

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Supplementary

Table S1 Studies included in the meta–analysis

First Author	Title	Year Published	Journal	Study Date	Type of Study	Number of Patients	Total NOS score
Bennetts	Left ventricular reconstruction by modified linear technique with absorbable suture.	2007	Heart, lung & circulation	1999–2004	Prospective	52	6
Goh	Surgical ventricular restoration procedure: single-center comparison of Surgical Treatment of Ischemic Heart Failure (STICH) versus non-STICH patients.	2013	The Annals of thoracic surgery	2002–2006	Prospective	21	6
Raman	Failure modes of left ventricular reconstruction or the Dor procedure: a multi-institutional perspective.	2006	European journal of cardio-thoracic surgery	1997–2005	Retrospective	284	5
Bove	Short-term systolic and diastolic ventricular performance after surgical ventricular restoration for dilated ischemic cardiomyopathy.	2009	European journal of cardio-thoracic surgery	2005–2008	Retrospective	23	7
Silveira	A bovine pericardium rigid prosthesis for left ventricle restoration: 12 years of follow-up.	2011	Revista brasileira de cirurgia cardiovascular	1999–2007	Retrospective	72	6
Contreras	Left Ventricular Reconstruction Surgery in Candidates for Heart Transplantation.	2019	Brazilian journal of cardiovascular surgery	2010–2016	Retrospective	34	6
Prates	Late results of endoventricular patch plasty repair in akinetic and dyskinetic areas after acute myocardial infarction.	2002	Arquivos brasileiros de cardiologia	1991–2000	Retrospective	52	6
Gomes	The renewed concept of the Batista operation for ischemic cardiomyopathy: maximum ventricular reduction.	2011	Revista brasileira de cirurgia cardiovascular	2002–2008	Prospective	76	6
Campagnucci	Left ventricular aneurysmectomy with continuous beating heart: Early results	2006	Brazilian Journal of Cardiovascular Surgery	1997–2005	Retrospective	34	5
Mickleborough	Left ventricular reconstruction: Early and late results.	2004	The Journal of thoracic and cardiovascular surgery	1983–2002	Prospective	285	7
Wei	Left Ventricular Aneurysm Repair: Off-pump Linear Plication versus On-pump Patch Plasty.	2019	Brazilian journal of cardiovascular surgery	2006–2016	Retrospective	90	8
Cui	The Pacopexy procedure for left ventricular aneurysm: a 10-year clinical experience.	2020	Surgery today	1998–2015	Retrospective	92	6
Song	Results of Left Ventricular Reconstruction With and Without Mitral Valve Surgery.	2020	The Annals of thoracic surgery	1999–2017	Retrospective	523	7
Liu	Role of surgical ventricular restoration in the treatment of ischemic cardiomyopathy.	2013	The Annals of thoracic surgery	1998–2008	Case control	94	8
Yan	Impact of surgical ventricular restoration on early and long-term outcomes of patients with left ventricular aneurysm: A single-center experience.	2018	Medicine	2005–2015	Retrospective	102	5
Zheng	Single-centre experience with perioperative use of hypothermic fibrillatory arrest without aortic occlusion in left ventricular aneurysm resection concomitant with on-pump coronary artery bypass grafting	2017	Surgical Practice	2005–2012	Retrospective	12	5
Wang	Early results after surgical treatment of left ventricular aneurysm.	2012	Journal of cardiothoracic surgery	2000–2009	Retrospective	61	7
Lange	Absent long-term benefit of patch versus linear reconstruction in left ventricular aneurysm surgery.	2005	The Annals of thoracic surgery	1974–2000	Retrospective	305	7
Coskun	Surgical treatment of left ventricular aneurysm.	2009	Asian cardiovascular & thoracic annals	1993–2002	Retrospective	269	6
Doss	Long term follow up of left ventricular function after repair of left ventricular aneurysm. A comparison of linear closure versus patch plasty.	2001	European journal of cardio-thoracic surgery	1989–1996	Retrospective	52	7
Dill	Pre- and postoperative assessment of left ventricular function by magnetic resonance imaging and 2-D-echocardiography in patients undergoing left ventricular aneurysmectomy.	2004	The Thoracic and cardiovascular surgeon	1998–2001	Retrospective	31	4
Bechtel	The extent of akinesis is predictive of the in-hospital mortality from endoaneurysmorrhaphy	2005	Zeitschrift fur Kardiologie	1993–1999	Retrospective	147	5
Huther	Cardiac magnetic resonance imaging for the assessment of ventricular function, geometry, and viability before and after surgical ventricular reconstruction.	2011	The Journal of thoracic and cardiovascular surgery	2002–2008	Retrospective	24	5
Dardas	Left atrial function and work after surgical ventricular restoration in postmyocardial infarction heart failure.	2008	Journal of the American Society of Echocardiography	–	Prospective	15	4
Hartyanszky	Personalized surgical repair of left ventricular aneurysm with computer-assisted ventricular engineering.	2014	Interactive cardiovascular and thoracic surgery	1999–2013	Prospective	41	6

Table S1 (*continued*)

Table S1 (continued)							
First Author	Title	Year Published	Journal	Study Date	Type of Study	Number of Patients	Total NOS score
Rajakumar	Role of surgical ventricular restoration post surgical treatment of heart failure (STICH) trial	2019	Indian Journal of Thoracic and Cardiovascular Surgery	2009–2016	Retrospective	49	9
Jain	Beneficial effects of endoventricular circular patch plasty in patients with left ventricular systolic dysfunction and left ventricular dyskinetic or akinetic apical segment	2007	Indian Journal of Thoracic and Cardiovascular Surgery	–	Prospective	39	4
Haranal	Post infarction left ventricular aneurysm—our experience	2018	Indian Journal of Thoracic and Cardiovascular Surgery	2009–2013	Retrospective	25	6
Adhyapak	Stroke volume paradox in heart failure: mathematical validation.	2014	Asian cardiovascular & thoracic annals	2003–2006	Prospective	101	4
Dmello	Postmyocardial infarction left ventricular dysfunction - assessment and follow up of patients undergoing surgical ventricular restoration by the endoventricular patchplasty.	2013	Indian heart journal	2007–2008	Retrospective	52	5
Mandegar	Long-term effect of papillary muscle approximation combined with ventriculoplasty on left ventricle function in patients with ischemic cardiomyopathy and functional mitral regurgitation.	2011	European journal of cardio-thoracic surgery	2004–2005	Retrospective	30	4
Pocar	Predictors of adverse events after surgical ventricular restoration for advanced ischaemic cardiomyopathy.	2010	European journal of cardio-thoracic surgery	2000–2007	Retrospective	31	7
Castelvecchio	Longitudinal profile of NT-proBNP levels in ischemic heart failure patients undergoing surgical ventricular reconstruction: The Biomarker Plus study.	2018	International Journal of Cardiology	2012–2014	Prospective	143	7
Garatti	Surgical ventricular restoration: is there any difference in outcome between anterior and posterior remodeling?.	2015	The Annals of thoracic surgery	2001–2011	Retrospective	501	7
Menicanti	Ischemic mitral regurgitation: intraventricular papillary muscle imbrication without mitral ring during left ventricular restoration.	2002	The Journal of thoracic and cardiovascular surgery	1998–2000	Retrospective	46	4
Ferrazzi	Surgical ventricular restoration by means of a new technique to preserve left ventricular compliance: the horseshoe repair.	2008	The Journal of thoracic and cardiovascular surgery	2005–2006	Retrospective	15	5
Cirillo	Determinants of postinfarction remodeling affect outcome and left ventricular geometry after surgical treatment of ischemic cardiomyopathy.	2004	The Journal of thoracic and cardiovascular surgery	1997–2002	Prospective	45	7
Cirillo	Time series analysis of physiologic left ventricular reconstruction in ischemic cardiomyopathy.	2016	The Journal of thoracic and cardiovascular surgery	2006–2013	Prospective	29	6
Nardi	Long-term outcomes after surgical ventricular restoration and coronary artery bypass grafting in patients with postinfarction left ventricular anterior aneurysm.	2010	Journal of cardiovascular medicine	1994–2004	Retrospective	104	7
Cotrufo	Acute hemodynamic and functional effects of surgical ventricular restoration and heart transplantation in patients with ischemic dilated cardiomyopathy.	2008	The Journal of thoracic and cardiovascular surgery	2004–2006	Prospective	35	6
Cotrufo	Treatment of extensive ischemic cardiomyopathy: quality of life following two different surgical strategies.	2005	European journal of cardio-thoracic surgery	1996–2003	Retrospective	42	6
Calafiore	Left ventricular surgical restoration for anteroseptal scars: volume versus shape.	2010	The Journal of thoracic and cardiovascular surgery	1988–2008	Retrospective	308	7
Tanoue	Ventricular energetics in endoventricular circular patch plasty for dyskinetic anterior left ventricular aneurysm.	2003	The Annals of thoracic surgery	1994–2002	Retrospective	8	5
Fujii	Radionuclide study of mid-term left ventricular function after endoventricular circular patch plasty.	2004	European journal of cardio-thoracic surgery	–	Prospective	14	6
Ishikawa	Early results and operative considerations of endoventricular circular patch plasty for ischemic cardiomyopathy.	2002	Japanese heart journal	1998–2000	Retrospective	7	4
Yoshida	Prediction of long-term survival in patients with end-stage heart failure secondary to ischemic heart disease: Surgical correction and volumetric analysis	2015	Annals of Thoracic and Cardiovascular Surgery	2000–2012	Retrospective	74	6

Table S1 (*continued*)

Table S1 *(continued)*

First Author	Title	Year Published	Journal	Study Date	Type of Study	Number of Patients	Total NOS score
Wakasa	Surgical strategy for ischemic mitral regurgitation adopting subvalvular and ventricular procedures.	2015	Annals of thoracic and cardiovascular surgery	1999–2013	Retrospective	34	7
Ueno	Mid-term changes of left ventricular geometry and function after Dor, SAVE, and Overlapping procedures.	2007	European journal of cardio-thoracic surgery	2000–2005	Retrospective	43	6
Kokaji	Changes in left ventricular volume and predictors of cardiac events after endoventricular circular patch plasty.	2004	The Japanese journal of thoracic and cardiovascular surgery	1996–2003	Prospective	30	7
Shimamoto	Clinical impact of diastolic function after surgical ventricular restoration.	2014	Asian cardiovascular & thoracic annals	1999–2012	Retrospective	71	6
Yamazaki	Impact of right ventricular volume and function evaluated using cardiovascular magnetic resonance imaging on outcomes after surgical ventricular reconstruction.	2018	European journal of cardio-thoracic surgery	2004–2016	Retrospective	53	6
Furukawa	Significance of preoperative right ventricular function on mid-term outcomes after surgical ventricular restoration for ischemic cardiomyopathy.	2019	General thoracic and cardiovascular surgery	2010–2016	Retrospective	19	6
Yamaguchi	Left ventricular reconstruction benefits patients with dilated ischemic cardiomyopathy.	2005	The Annals of thoracic surgery	1990–2004	Retrospective	20	7
Takeda	Long-term results of left ventricular reconstructive surgery in patients with ischemic dilated cardiomyopathy: a multicenter study.	2008	Circulation journal : official journal of the Japanese Circulation Society	1999–2007	Retrospective	72	6
Yamaguchi	Reduction of mitral valve leaflet tethering by procedures targeting the subvalvular apparatus in addition to mitral annuloplasty.	2013	Circulation journal: official journal of the Japanese Circulation Society	2007–2012	Retrospective	8	4
Kato	Surgical treatment of functional mitral regurgitation involving the subvalvular apparatus.	2015	Journal of cardiac surgery	2004–2012	Retrospective	15	5
Suma	Nontransplant cardiac surgery for end-stage cardiomyopathy.	2000	The Journal of thoracic and cardiovascular surgery	1996–1999	Prospective	33	7
Nakamura	Efficacy of modified endoventricular circular patch plasty in ischemic cardiomyopathy--innovative delimitation technique using integrated myocardial management.	2003	Journal of cardiac surgery	1998–2001	Prospective	14	6
Cho	Long-term results and mid-term features of left ventricular reconstruction procedures on left ventricular volume, geometry, function and mitral regurgitation.	2012	European journal of cardio-thoracic surgery	2002–2010	Prospective	60	7
Sawazaki	Endoventricular left ventriculoplasty: Overlap technique for akinetic scar	2000	Asian Cardiovascular and Thoracic Annals	1998–1998	Case Series	4	5
Butkuviene	The impact of surgical ventricular restoration on ischemic mitral regurgitation.	2011	Medicina	1999–2006	Retrospective	139	6
Di Donato	Effects of the Dor procedure on left ventricular dimension and shape and geometric correlates of mitral regurgitation one year after surgery.	2001	The Journal of thoracic and cardiovascular surgery	1997–1998	Retrospective	44	4
Di Donato	Intermediate survival and predictors of death after surgical ventricular restoration.	2001	Seminars in thoracic and cardiovascular surgery	1991–1996	Retrospective	207	7
Dor	Favorable effects of left ventricular reconstruction in patients excluded from the Surgical Treatments for Ischemic Heart Failure (STICH) trial.	2011	The Journal of thoracic and cardiovascular surgery	2002–2008	Prospective	117	7
Couperus	Right ventricular dysfunction after surgical left ventricular restoration: prevalence, risk factors and clinical implications.	2017	European journal of cardio-thoracic surgery	2006–2014	Prospective	86	6
Grandjean	Endoventriculoplasty using autologous endocardium for anterior left ventricular aneurysms	2005	Thoracic and Cardiovascular Surgeon	1990–2013	Retrospective	49	5
Lundblad	Surgery for left ventricular aneurysm: early and late survival after simple linear repair and endoventricular patch plasty.	2004	The Journal of thoracic and cardiovascular surgery	1989–2003	Retrospective	159	6
Bockeria	Left ventricular geometry reconstruction in ischemic cardiomyopathy patients with predominantly hypokinetic left ventricle.	2006	European journal of cardio-thoracic surgery	–	Prospective	14	5
Marchenko	Results of coronary artery bypass grafting alone and combined with surgical ventricular reconstruction for ischemic heart failure.	2011	Interactive cardiovascular and thoracic surgery	2005–2008	Retrospective	116	7
Marchenko	Left ventricular dimension and shape after postinfarction aneurysm repair.	2005	European journal of cardio-thoracic surgery	1997–2003	Retrospective	158	7

Table S1 *(continued)*

Table S1 (*continued*)

First Author	Title	Year Published	Journal	Study Date	Type of Study	Number of Patients	Total NOS score
Babokin	Surgical ventricular reconstruction with endocardectomy along radiofrequency ablation-induced markings.	2013	The Journal of thoracic and cardiovascular surgery	2005–2011	Retrospective	168	5
Shipulin	Causes of repeated remodeling of left ventricle after Dor procedure.	2007	Interactive cardiovascular and thoracic surgery	1991–2007	Retrospective	36	7
Zhong	Improved aorto-ventricular matching in ischemic dilated cardiomyopathy patients after surgical ventricular restoration.	2011	Medical engineering & physics	–	Retrospective	4	5
Hwang	Surgical anterior ventricular endocardial restoration performed with total arterial revascularization: serial 5-year follow-up.	2014	The Journal of thoracic and cardiovascular surgery	1999–2005	Prospective	63	6
Lee	Changes in left ventricular function and dimension after surgical ventricular restoration with or without concomitant mitral valve procedure.	2007	Circulation journal : official journal of the Japanese Circulation Society	2001–2006	Prospective	49	6
Sartipy	The Dor procedure for left ventricular reconstruction. Ten-year clinical experience.	2005	European journal of cardio-thoracic surgery	1994–2004	Prospective	101	7
Yu	Why is the surgical ventricular restoration operation effective for ischemic cardiomyopathy? Geometric analysis with magnetic resonance imaging of changes in regional ventricular function after surgical ventricular restoration.	2009	The Journal of thoracic and cardiovascular surgery	–	Prospective	10	5
Chen	Left ventricular aneurysm repair: a comparison of linear versus patch remodeling.	2009	Journal of the Chinese Medical Association: JCMA	1996–2006	Retrospective	49	6
Kaya	Application of Circular Patch Plasty (Dor Procedure) or Linear Repair Techniques in the Treatment of Left Ventricular Aneurysms.	2018	Brazilian journal of cardiovascular surgery	1996–2016	Retrospective	89	8
Tekumit	Left ventricular aneurysm using the Dor technique: mid-term results.	2010	Journal of cardiac surgery	2001–2009	Retrospective	67	7
Kosar	Effects of coronary revascularization and concomitant aneurysmectomy on QT interval duration and dispersion.	2006	Journal of electrocardiology	2001–2004	Prospective	43	7
Toker	Posterobasal left ventricular aneurysms: surgical treatment and long-term outcomes.	2013	Texas Heart Institute journal	1993–2009	Retrospective	18	5
Kalkat	Left ventricular aneurysmectomy: tailored scar excision and linear closure.	2006	Asian cardiovascular & thoracic annals	1992–2003	Retrospective	102	6
Oneill	The impact of left ventricular reconstruction on survival in patients with ischemic cardiomyopathy.	2006	European journal of cardio-thoracic surgery	1997–2003	Retrospective	220	6
Skelley	The impact of volume reduction on early and long-term outcomes in surgical ventricular restoration for severe heart failure.	2011	The Annals of thoracic surgery	2002–2008	Retrospective	87	6
Hobbs	Long-Term Survival and Echocardiographic Findings After Surgical Ventricular Restoration.	2019	The Annals of thoracic surgery	1992–2017	Retrospective	109	7
Adams	Does preoperative ejection fraction predict operative mortality with left ventricular restoration?.	2006	The Annals of thoracic surgery	1996–2005	Retrospective	89	6
Aliyev	Left Ventricular Aneurysm Repair with Endoaneurysmorrhaphy Technique: An Assessment of Two Different Ventriculotomy Closure Methods.	2016	The heart surgery forum	1997–2009	Retrospective	73	5
Castiglioni	Surgical restoration of the left ventricle for postinfarction aneurysm.	2002	Italian heart journal	1997–2001	Retrospective	94	6
Roscitano	Left ventricular aneurysm repair: early survival.	2005	Italian heart journal	1993–2003	Retrospective	51	6
Soloman	Surgical repair of left ventricular aneurysms: a comparative evaluation of linear versus Dor's repair.	2001	Indian Heart Journal	1988–2001	Retrospective	95	5
Stefaneli	Cell therapy and left ventricular restoration for ischemic cardiomyopathy: long-term results of a perspective, randomized study	2019	Minerva Cardioangiologica	2007–2013	Prospective	14	7

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Table S2 Newcastle–Ottawa Scale Bias Assessment

Study title	Representative of the exposed cohort	Selection of the nonexposed cohort	Ascertainment of exposure	Outcome of interest was not present at start of study	Comparability of cohorts on the bases of the design or analysis	Assessment of outcome	Was follow-up long enough for outcome to occur	Adequacy of followup	Total
Left ventricular reconstruction by modified linear technique with absorbable suture.	1	0	1	1	0	1	1	1	6
Surgical ventricular restoration procedure: single-center comparison of Surgical Treatment of Ischemic Heart Failure (STICH) versus non-STICH patients.	1	0	1	1	0	1	1	1	6
Failure modes of left ventricular reconstruction or the Dor procedure: a multi-institutional perspective.	1	0	1	1	0	1	1	0	5
Short-term systolic and diastolic ventricular performance after surgical ventricular restoration for dilated ischemic cardiomyopathy.	1	1	1	1	0	1	1	1	7
A bovine pericardium rigid prosthesis for left ventricle restoration: 12 years of follow-up.	1	0	1	1	0	1	1	1	6
Left Ventricular Reconstruction Surgery in Candidates for Heart Transplantation.	1	0	1	1	0	1	1	1	6
Late results of endoventricular patch plasty repair in akinetic and dyskinetic areas after acute myocardial infarction.	1	0	1	1	0	1	1	1	6
The renewed concept of the Batista operation for ischemic cardiomyopathy: maximum ventricular reduction.	1	0	1	1	0	1	1	1	6
Left ventricular aneurysmectomy with continuous beating heart: Early results	1	0	1	1	0	1	0	1	5
Left ventricular reconstruction: Early and late results.	1	0	1	1	1	1	1	1	7
Left Ventricular Aneurysm Repair: Off-pump Linear Plication versus On-pump Patch Plasty.	1	0	1	1	2	1	1	1	8
The Pacopexy procedure for left ventricular aneurysm: a 10-year clinical experience.	1	0	1	1	0	1	1	1	6
Results of Left Ventricular Reconstruction With and Without Mitral Valve Surgery.	1	0	1	1	1	1	1	1	7
Role of surgical ventricular restoration in the treatment of ischemic cardiomyopathy.	1	1	1	1	1	1	1	1	8
Impact of surgical ventricular restoration on early and long-term outcomes of patients with left ventricular aneurysm: A single-center experience.	1	0	1	1	0	1	1	0	5
Single-centre experience with perioperative use of hypothermic fibrillatory arrest without aortic occlusion in left ventricular aneurysm resection concomitant with on-pump coronary artery bypass grafting	0	0	1	1	0	1	1	1	5
Early results after surgical treatment of left ventricular aneurysm.	1	0	1	1	1	1	1	1	7
Absent long-term benefit of patch versus linear reconstruction in left ventricular aneurysm surgery.	1	0	1	1	1	1	1	1	7
Surgical treatment of left ventricular aneurysm.	1	0	1	1	0	1	1	1	6
Long term follow up of left ventricular function after repair of left ventricular aneurysm. A comparison of linear closure versus patch plasty.	1	0	1	1	2	1	1	0	7

Table S2 (*continued*)

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Table S2 (*continued*)

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Pre- and postoperative assessment of left ventricular function by magnetic resonance imaging and 2-D-echocardiography in patients undergoing left ventricular aneurysmectomy.	0	0	1	1	0	1	0	1	4
The extent of akinesis is predictive of the in-hospital mortality from endoaneurysmorrhaphy	1	0	1	1	1	1	0	1	5
Cardiac magnetic resonance imaging for the assessment of ventricular function, geometry, and viability before and after surgical ventricular reconstruction.	0	0	1	1	0	1	1	1	5
Left atrial function and work after surgical ventricular restoration in postmyocardial infarction heart failure.	0	0	1	1	0	1	0	1	4
Personalized surgical repair of left ventricular aneurysm with computer-assisted ventricular engineering.	1	0	1	1	0	1	1	1	6
Role of surgical ventricular restoration post surgical treatment of heart failure (STICH) trial	1	1	1	1	2	1	1	1	9
Beneficial effects of endoventricular circular patch plasty in patients with left ventricular systolic dysfunction and left ventricular dyskinetic or akinetic apical segment	1	0	1	1	0	1	0	0	4
Post infarction left ventricular aneurysm—our experience	1	0	1	1	0	1	1	1	6
Stroke volume paradox in heart failure: mathematical validation.	1	0	1	1	0	1	0	0	4
Postmyocardial infarction left ventricular dysfunction - assessment and follow up of patients undergoing surgical ventricular restoration by the endoventricular patchplasty.	1	0	1	1	0	1	0	1	5
Long-term effect of papillary muscle approximation combined with ventriculoplasty on left ventricle function in patients with ischemic cardiomyopathy and functional mitral regurgitation.	0	0	1	1	0	1	1	0	4
Predictors of adverse events after surgical ventricular restoration for advanced ischaemic cardiomyopathy.	0	0	1	1	2	1	1	1	7
Longitudinal profile of NT-proBNP levels in ischemic heart failure patients undergoing surgical ventricular reconstruction: The Biomarker Plus study.	1	0	1	1	1	1	1	1	7
Surgical ventricular restoration: is there any difference in outcome between anterior and posterior remodeling?.	1	0	1	1	1	1	1	1	7
Ischemic mitral regurgitation: intraventricular papillary muscle imbrication without mitral ring during left ventricular restoration.	0	0	1	1	1	1	0	0	4
Surgical ventricular restoration by means of a new technique to preserve left ventricular compliance: the horseshoe repair.	0	0	1	1	1	1	0	1	5
Determinants of postinfarction remodeling affect outcome and left ventricular geometry after surgical treatment of ischemic cardiomyopathy.	1	0	1	1	1	1	1	1	7
Time series analysis of physiologic left ventricular reconstruction in ischemic cardiomyopathy.	1	0	1	0	1	1	1	1	6

Table S2 (*continued*)

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Table S2 (*continued*)									
Study title	Representative of the exposed cohort	Selection of the nonexposed cohort	Ascertainment of exposure	Outcome of interest was not present at start of study	Comparability of cohorts on the bases of the design or analysis	Assessment of outcome	Was follow-up long enough for outcome to occur	Adequacy of followup	Total
Long-term outcomes after surgical ventricular restoration and coronary artery bypass grafting in patients with postinfarction left ventricular anterior aneurysm.	1	0	1	1	1	1	1	1	7
Acute hemodynamic and functional effects of surgical ventricular restoration and heart transplantation in patients with ischemic dilated cardiomyopathy.	1	0	1	1	1	1	0	1	6
Treatment of extensive ischemic cardiomyopathy: quality of life following two different surgical strategies.	1	0	1	1	1	0	1	1	6
Left ventricular surgical restoration for anteroseptal scars: volume versus shape.	1	1	1	1	1	1	1	0	7
Ventricular energetics in endoventricular circular patch plasty for dyskinetic anterior left ventricular aneurysm.	0	0	1	1	1	1	0	1	5
Radionuclide study of mid-term left ventricular function after endoventricular circular patch plasty.	0	0	1	1	1	1	1	1	6
Early results and operative considerations of endoventricular circular patch plasty for ischemic cardiomyopathy.	0	0	1	1	0	1	0	1	4
Prediction of long-term survival in patients with end-stage heart failure secondary to ischemic heart disease: Surgical correction and volumetric analysis	1	0	1	1	1	1	1	0	6
Surgical strategy for ischemic mitral regurgitation adopting subvalvular and ventricular procedures.	1	0	1	1	1	1	1	1	7
Mid-term changes of left ventricular geometry and function after Dor, SAVE, and Overlapping procedures.	1	0	1	1	1	1	0	1	6
Changes in left ventricular volume and predictors of cardiac events after endoventricular circular patch plasty.	1	0	1	1	1	1	1	1	7
Clinical impact of diastolic function after surgical ventricular restoration.	0	0	1	1	1	1	1	1	6
Impact of right ventricular volume and function evaluated using cardiovascular magnetic resonance imaging on outcomes after surgical ventricular reconstruction.	1	0	1	1	1	1	1	0	6
Significance of preoperative right ventricular function on mid-term outcomes after surgical ventricular restoration for ischemic cardiomyopathy.	0	0	1	1	1	1	1	1	6
Left ventricular reconstruction benefits patients with dilated ischemic cardiomyopathy.	1	0	1	1	1	1	1	1	7
Long-term results of left ventricular reconstructive surgery in patients with ischemic dilated cardiomyopathy: a multicenter study.	1	0	1	1	1	1	1	0	6
Reduction of mitral valve leaflet tethering by procedures targeting the subvalvular apparatus in addition to mitral annuloplasty.	0	0	1	0	1	1	0	1	4
Surgical treatment of functional mitral regurgitation involving the subvalvular apparatus.	0	0	1	1	1	1	1	0	5
Nontransplant cardiac surgery for end-stage cardiomyopathy.	1	0	1	1	1	1	1	1	7
Table S2 (*continued*)									

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Table S2 (*continued*)									
Study title	Representative of the exposed cohort	Selection of the nonexposed cohort	Ascertainment of exposure	Outcome of interest was not present at start of study	Comparability of cohorts on the bases of the design or analysis	Assessment of outcome	Was follow-up long enough for outcome to occur	Adequacy of followup	Total
Efficacy of modified endoventricular circular patch plasty in ischemic cardiomyopathy--innovative delimitation technique using integrated myocardial management.	1	0	1	1	1	1	0	1	6
Long-term results and mid-term features of left ventricular reconstruction procedures on left ventricular volume, geometry, function and mitral regurgitation.	1	0	1	1	1	1	1	1	7
Endoventricular left ventriculoplasty: Overlap technique for akinetic scar	0	0	1	1	1	1	0	1	5
The impact of surgical ventricular restoration on ischemic mitral regurgitation.	1	0	1	1	1	1	1	0	6
Effects of the Dor procedure on left ventricular dimension and shape and geometric correlates of mitral regurgitation one year after surgery.	1	0	1	0	1	1	0	0	4
Intermediate survival and predictors of death after surgical ventricular restoration.	1	0	1	1	1	1	1	1	7
Favorable effects of left ventricular reconstruction in patients excluded from the Surgical Treatments for Ischemic Heart Failure (STICH) trial.	1	0	1	1	1	1	1	1	7
Right ventricular dysfunction after surgical left ventricular restoration: prevalence, risk factors and clinical implications.	0	0	1	1	1	1	1	1	6
Endoventriculoplasty using autologous endocardium for anterior left ventricular aneurysms	1	0	1	1	0	1	0	1	5
Surgery for left ventricular aneurysm: early and late survival after simple linear repair and endoventricular patch plasty.	0	0	1	1	1	1	1	1	6
Left ventricular geometry reconstruction in ischemic cardiomyopathy patients with predominantly hypokinetic left ventricle.	0	0	1	1	1	1	0	1	5
Results of coronary artery bypass grafting alone and combined with surgical ventricular reconstruction for ischemic heart failure.	1	0	1	1	1	1	1	1	7
Left ventricular dimension and shape after postinfarction aneurysm repair.	1	1	1	1	1	1	1	0	7
Surgical ventricular reconstruction with endocardectomy along radiofrequency ablation-induced markings.	1	0	1	1	1	1	0	0	5
Causes of repeated remodeling of left ventricle after Dor procedure.	1	1	1	1	1	1	0	1	7
Improved aorto-ventricular matching in ischemic dilated cardiomyopathy patients after surgical ventricular restoration.	0	0	1	1	1	1	0	1	5
Surgical anterior ventricular endocardial restoration performed with total arterial revascularization: serial 5-year follow-up.	1	0	1	1	1	1	1	0	6
Changes in left ventricular function and dimension after surgical ventricular restoration with or without concomitant mitral valve procedure.	0	0	1	1	1	1	1	1	6
The Dor procedure for left ventricular reconstruction. Ten-year clinical experience.	1	0	1	1	1	1	1	1	7

Table S2 (*continued*)

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Table S2 (continued)									
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Why is the surgical ventricular restoration operation effective for ischemic cardiomyopathy? Geometric analysis with magnetic resonance imaging of changes in regional ventricular function after surgical ventricular restoration.	1	0	1	1	0	1	0	1	5
Left ventricular aneurysm repair: a comparison of linear versus patch remodeling.	1	0	1	0	1	1	1	1	6
Application of Circular Patch Plasty (Dor Procedure) or Linear Repair Techniques in the Treatment of Left Ventricular Aneurysms.	1	1	1	1	1	1	1	1	8
Left ventricular aneurysm using the Dor technique: mid-term results.	1	0	1	1	1	1	1	1	7
Effects of coronary revascularization and concomitant aneurysmectomy on QT interval duration and dispersion.	1	0	1	1	1	1	1	1	7
Posterobasal left ventricular aneurysms: surgical treatment and long-term outcomes.	0	0	1	1	0	1	1	1	5
Left ventricular aneurysmectomy: tailored scar excision and linear closure.	1	0	1	1	0	1	1	1	6
The impact of left ventricular reconstruction on survival in patients with ischemic cardiomyopathy.	1	0	1	1	0	1	1	1	6
The impact of volume reduction on early and long-term outcomes in surgical ventricular restoration for severe heart failure.	1	0	1	1	0	1	1	1	6
Long-Term Survival and Echocardiographic Findings After Surgical Ventricular Restoration.	1	0	1	1	1	1	1	1	7
Does preoperative ejection fraction predict operative mortality with left ventricular restoration?.	1	0	1	1	1	1	1	0	6
Left Ventricular Aneurysm Repair with Endoaneurysmorrhaphy Technique: An Assessment of Two Different Ventriculotomy Closure Methods.	0	0	1	1	1	1	1	0	5
Surgical restoration of the left ventricle for postinfarction aneurysm.	1	0	1	1	0	1	1	1	6
Left ventricular aneurysm repair: early survival.	1	0	1	1	0	1	1	1	6
Surgical repair of left ventricular aneurysms: a comparative evaluation of linear versus Dor's repair.	1	0	1	1	0	1	1	0	5
Cell therapy and left ventricular restoration for ischemic cardiomyopathy: long-term results of a perspective, randomized study	1	0	1	1	1	1	1	1	7

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