Contemporary experience with the Commando procedure for anterior mitral anular calcification

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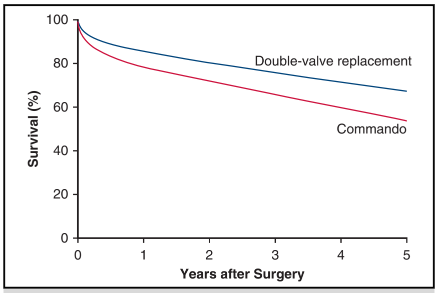
ABSTRACT

Objective: Anterior mitral anular calcification, particularly in radiation heart disease, and previous valve replacement with destroyed intervalvular fibrosa are challenging for prosthesis sizing and placement. The Commando procedure with intervalvular fibrosa reconstruction permits double-valve replacement in these challenging conditions. We referenced outcomes after Commando procedures to standard double-valve replacements.

Methods: From January 2011 to January 2022, 129 Commando procedures and 1191 aortic and mitral double-valve replacements were performed at the Cleveland Clinic, excluding endocarditis. Reasons for the Commando were severe calcification after radiation (n = 67), without radiation (n = 43), and others (n = 19). Commando procedures were referenced to a subset of double-valve replacements using balancing-score methods (109 pairs).

Results: Between balanced groups, Commando versus double-valve replacement had higher total calcium scores (median 6140 vs 2680 HU, $P = .03$). Hospital outcomes were similar, including operative mortality (12/11% vs 8/7.3%, $P = .35$) and reoperation for bleeding (9/8.3% vs 5/4.6%, $P = .28$). Survival and freedom from reoperation at 5 years were 54% versus 67% ($P = .33$) and 87% versus 100% ($P = .04$), respectively. Higher calcium score was associated with lower survival after double-valve replacement but not after the Commando. The Commando procedure had lower aortic valve mean gradients at 4 years (9.4 vs 11 mm Hg, $P = .04$). After Commando procedures for calcification, 5-year survival was 60% and 59% with and without radiation, respectively ($P = .47$).

Conclusions: The Commando procedure with reconstruction of the intervalvular fibrosa destroyed by mitral anular calcification, radiation, or previous surgery demonstrates acceptable outcomes similar to standard double-valve replacement. More experience and long-term outcomes are required to refine patient selection for and application of the Commando approach. (JTCVS Open 2024;18:12-30)



Survival after the Commando procedure and DVR surgery in balanced cohorts.

CENTRAL MESSAGE

Intervalvular fibrosa reconstruction (Commando procedure) for radiation and calcification demonstrated midterm outcomes similar to DVR, with later survival curve dissociation.

PERSPECTIVE

Destruction of the intervalvular fibrosa by severe calcification, particularly when caused by radiation, or for other reasons, presents challenges to prosthesis sizing and placement when aortic and mitral valve replacement are required. The Commando procedure for reconstructing the intervalvular fibrosa has acceptable outcomes similar to those of DVR.

See Discussion on page 31.

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Abbreviations and Acronyms
CT = computed tomography
DVR = double-valve replacement
HU = Hounsfield units

Video clip is available online.

To view the AATS Annual Meeting Webcast, see the URL next to the webcast thumbnail.

Nearly 3 decades ago, the Commando procedure was introduced for reconstructing the intervalvular fibrosa (aortomitral curtain) to address its destruction by infective endocarditis.[1-5] With increasing experience, its indications broadened to noninfectious conditions, including severe intervalvular fibrosa calcification of radiation-associated mitral anular calcification, with or without radiation-associated cardiac disease, and other situations where simultaneous aortic and mitral valve replacement (double-valve replacement [DVR]) is complicated by insufficient healthy intervalvular fibrosa tissue to secure the new prostheses, as in patients who have undergone previous valve operations.[6-8]

In patients with radiation heart disease, the intervalvular fibrosa is commonly calcified and thickened out of proportion to other areas of valvular calcification,[9,10] presenting challenges for prosthesis sizing and implant in DVR. Mitral anular calcification without radiation is encountered with increasing frequency, especially in the elderly in developed countries,[11,12] together with improved life expectancy in patients with radiation heart disease in whom the mitral anular calcification-related mitral valve dysfunction is common.[9,10,12] Therefore, it is necessary to understand the value and effect of intervalvular fibrosa reconstruction on valve hemodynamics, hospital outcomes, and survival in these challenging conditions. We sought to evaluate early and intermediate-term outcomes of Commando procedures performed for noninfective endocarditis pathologies and reference these outcomes to a subgroup of patients with similar demographics and comorbidities undergoing standard DVR in which the intervalvular fibrosa is preserved.

PATIENTS AND METHODS

Patients

From January 2011 to January 2022, 1525 patients underwent DVR at Cleveland Clinic. Of these, 129 underwent a Commando procedure for indications other than infective endocarditis, and 1191 underwent standard DVR (Figure E1 and Tables 1 and E1).

Commando Procedure

Indications for the Commando procedure (Video 1) were intervalvular fibrosa calcification with (n = 67/52%) or without (n = 43/33%) radiation heart disease, and other (n = 19/15%) (Table 2). Bovine pericardium was used in 111 intervalvular fibrosa reconstructions (86%). Operative techniques have been described.[8] Recently, exposure of the mitral anulus via the left atrial dome was accomplished with a short incision; in challenging exposures, this incision was extended into the interatrial septum, in some cases requiring concomitant patch closure of the right atrium.[8] When there was severe circumferential calcification precluding safe aortic clamping, concomitant aortic root or ascending aorta replacement was performed.

Data

Preoperative patient, procedural, and perioperative outcome data were extracted from databases abstracted prospectively for quality assurance by independent registry personnel. Valve gradient and regurgitation data were extracted from the Echocardiography Database. All data used for this study were approved for use in research by the Cleveland Clinic Institutional Review Board, with patient consent waived (#22-636, approved June 29, 2022).

Calcium Measurements

For 56 Commando and 47 DVR matched patients, aortic valve, mitral valve, intervalvular fibrosa, and total calcium scores were measured on available preoperative cardiac computed tomography (CT) images obtained mostly within 1 month before surgery expressed using Agatston scoring.[13,14] For noncontrast cardiac CT, a threshold of 130 Hounsfield units (HU) was used. For contrast-enhanced cardiac CT, the threshold was calculated as mean HU measured at the level of the left ventricular outflow tract and multiplied by 4 times the standard deviation (SD).

End Points

Morbidity and operative mortality. Hospital morbidity was defined as for the Society of Thoracic Surgeons National database.[15] Operative mortality included hospital deaths and deaths after hospital discharge to postoperative day 30.

Postoperative valve hemodynamics. For 119 of the 129 patients (93%) in the Commando group, 389 postoperative transthoracic echocardiograms were available, as were 332 for 90 of the 109 patients (83%) in the matched DVR group. From these, aortic and mitral regurgitation grade (none or trace, mild, moderate, or severe), aortic and mitral transvalvular mean gradient, and left ventricular ejection fraction were extracted. These longitudinal repeated measures were censored at valve reoperation.

Valve reoperation and mortality. Patients were followed systematically for vital status and aortic or mitral valve reoperations. Median follow-up of the Commando group was 1.5 years, with 25% followed more than 2.8 years and 10% more than 5 years. Median follow-up of the matched DVR group was 1.9 years, with 25% followed more than 4.6 years and 10% more than 5 years. Follow-up included medical records review, a questionnaire at 2 and 5 years postoperatively and every 5 years thereafter, and, if necessary, telephone contact using an Institutional Review Board–approved script with patient consent. Active follow-up was supplemented with passive Social Security Administration Death Master File data until 2011 and Ohio Death Registry vital status data thereafter. Median follow-up for vital status of the Commando group was 2.0 years, with 25% followed more than 4.5 years and 10% more than 6.9 years. Median

TABLE 1. Characteristics of full and matched cohorts of patients undergoing Commando and standard double-valve replacement

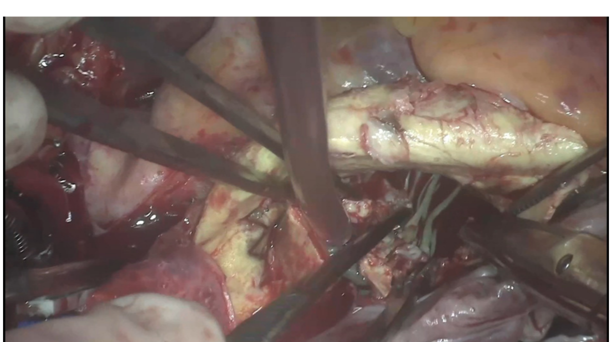
	Full cohorts					Matched cohorts				
	Commando (n = 129)			DVR (n = 1191)		Commando (n = 109)			DVR (n = 109)	
Characteristic	n*	No. (%) or Mean ± SD	Std. Diff. (%)	n*	No. (%) or Mean ± SD	n*	No. (%) or Mean ± SD	Std. Diff. (%)	n*	No. (%) or Mean ± SD
Demographics										
Age (y)	129	62 ± 12	−56	1191	68 ± 12	109	63 ± 12	8.7	109	61 ± 13
Female	129	78 (60)	18	1191	614 (52)	109	64 (59)	−3.7	109	66 (61)
Body mass index (kg/m^2)	129	28 ± 6.5	6.2	1191	28 ± 6.2	109	29 ± 6.7	−10	109	30 ± 6.9
Cardiac comorbidities										
Atrial fibrillation or flutter	128	40 (31)	−44	1174	615 (52)	108	36 (33)	−13	106	42 (40)
Heart failure	129	71 (55)	−18	1191	762 (64)	109	63 (58)	0	109	63 (58)
Left ventricular morphology and function										
End-diastolic volume index (mL/m^2)	121	45 ± 20	−71	1114	60 ± 26	103	46 ± 20	11	103	44 ± 18
End-systolic volume index (mL/m^2)	116	18 ± 11	−56	1095	26 ± 18	99	19 ± 11	14	102	17 ± 11
Ejection fraction (%)	128	59 ± 9.1	20	1187	57 ± 11	109	59 ± 9.3	−3.7	109	59 ± 11
Mass index (g/m^2)	120	94 ± 35	−65	1109	120 ± 44	102	98 ± 35	−6.4	103	99 ± 40
Aortic dimension										
Mid-ascending aorta diameter (cm)	110	3.03 ± 0.51	−56	1022	3.3 ± 0.59	94	3.1 ± 0.52	−2.1	97	3.1 ± 0.49
Noncardiac comorbidities										
Pharmacologically treated diabetes	129	29 (22)	−7.9	1183	306 (26)	109	23 (21)	−3.2	107	24 (22)
COPD	129	78 (60)	32	1191	535 (45)	109	62 (57)	1.9	109	61 (56)
Peripheral artery disease	129	13 (10)	0.29	1191	119 (10)	109	11 (10)	6.4	109	9 (8.3)
Hypertension	129	101 (78)	−6.4	1191	963 (81)	109	84 (77)	−4.4	109	86 (79)
Smoking	126	50 (40)	−21	1182	589 (50)	107	46 (43)	6.5	108	43 (40)
Creatinine (mg/dL)†	128	0.75/0.99/1.4‡	−22	1190	0.77/1.1/1.6‡	108	0.75/0.99/1.4‡	−14	109	0.77/1.0/1.6‡
Blood urea nitrogen (mg/dL)	126	24 ± 14	−11	1184	24 ± 14	106	24 ± 15	−8.6	107	24 ± 14
Bilirubin (mg/dL)†	125	0.30/0.50/0.91‡	−27	1104	0.40/0.60/1.2‡	105	0.30/0.50/1.0‡	4.0	103	0.30/0.50/1.0‡
Hematocrit (%)	128	37 ± 6.0	3.1	1190	37 ± 5.7	108	37 ± 6.1	−6.2	109	38 ± 6.0

SD, Standard deviation; *Std. Diff.*, standardized difference; *DVR*, double-valve replacement; *COPD*, chronic obstructive pulmonary disease. *Patients with data available. †Not included in balancing model. ‡15th/50th/85th percentiles.

follow-up for vital status of the matched DVR group was 2.6 years, with 25% followed more than 5.1 years and 10% more than 7.7 years.

Data Analysis

Statistical analyses were performed using SAS version 9.4 and R software version 3.6.0. Continuous variables are summarized as mean ± SD or equivalent 15th, 50th (median), and 85th percentiles when their distributions were skewed. Categorical data are summarized by frequencies and percentages. Differences between preoperative and operative characteristics of the Commando and DVR groups are expressed as standardized mean differences (%). CIs for longitudinal estimates used a bootstrap percentile method to obtain 68% confidence bands (equivalent to ±1 standard error) and the delta method for time-related events.



VIDEO 1. Highlights of the Commando procedure in a patient who does not have infective endocarditis as the indication for operation. Video available at: https://www.jtcvs.org/article/S2666-2736(23)00369-8/fulltext.

Referencing Commando to standard double-valve replacement outcomes.

Rationale. There are important reasons a Commando procedure is added to DVR that render the operations nonexchangeable (and thereby violating an underlying requirement for use of the propensity score), and characteristics of patients in these 2 groups (Table 1, Table E1) substantially differed. To identify what incremental difference in outcomes a Commando procedure adds to the risk of standard DVRs, we adopted the epidemiologic methods of "natural experiments" (originating with John Snow's investigation of the cholera outbreak in London in 1854).[16] For this, we identified a reference subgroup of standard DVRs using a balancing score based only on patient characteristics and cardiac conditions not directly related to the valve pathology.[17]

Missing values. For missing values (see n-available column, Table 1), we used 5-fold multiple imputation with multivariate imputation by chained equations.[18] In parsimonious multivariable modeling, for each imputed data set, we estimated regression coefficients and their variance–covariance matrix, and then combined estimates from the 5 models to yield final coefficient estimates, variance–covariance matrix, and *P* values.[18]

Balancing score development. Multivariable logistic regression was used to develop the parsimonious model to identify variables distinguishing the Commando group from the DVR group based on preoperative and concomitant procedure variables (Appendix E1). Variable selection,

TABLE 2. Reasons for Commando procedure in full and matched cohorts*

Reason	Full cohort Commando (n = 129) No. (%)	Matched cohorts Commando (n = 109) No. (%)	Matched cohorts DVR (n = 109) No. (%)
MAC	43 (33)	42 (39)	28 (26)
Radiation heart disease	67 (52)	50 (46)	20 (18)
Prosthesis–patient mismatch	10 (7.8)	8 (7.3)	2 (1.8)
Previous valve replacement failure	6 (4.7)	6 (5.5)	0 (0)
Structural valve deterioration	2 (1.6)	2 (1.8)	0 (0)
Outgrown valve	1 (0.78)	1 (0.92)	0 (0)
Unspecified	0 (0)	0 (0)	59 (54)

DVR, Double-valve replacement; *MAC*, mitral anular calcification. *These variables were not appropriate to include in constructing the balancing score for matching.

with a *P* less than .05 for variable retention, used bagging based on automated analysis of 1000 bootstrap data sets using the first imputed data set, followed by aggregating results of the model applied to all 5 imputed data sets (C-statistic = .80; Table E2).[19]

To this parsimonious model, we added additional variables representing demographics, symptoms, and cardiac and noncardiac comorbidities possibly related to unrecorded factors (saturated model with 66 variables; C-statistic = .85). A balancing score was calculated for each patient by solving this model for the probability of being in the Commando group from each of the 5 imputed data sets and averaging.[20]

Matching. Using the balancing score, Commando cases were matched 1:1 to standard DVR cases using a greedy-matching strategy[21] in the logit domain with a caliper width 0.2 times the SD of the logit of the propensity score, yielding 109 well-matched pairs (84% of Commando cases; Figure E2, *A* and *B*).[22] Comparison of in-hospital outcomes between the matched groups used the Wilcoxon rank-sum test for continuous responses and the chi-squared test or Fisher's exact test if appropriate for categorical variables, bearing in mind that these comparisons are to a reference DVR subgroup not exchangeable with the Commando group.

Longitudinal data analyses. Patterns of temporal change in ordinal postoperative aortic and mitral valve regurgitation grades from all follow-up transthoracic echocardiograms were analyzed using a nonlinear multiphase (temporal decomposition) mixed-effects cumulative logit regression model.[23] Because of low frequency, severe and moderate regurgitation were collapsed. Prevalence of individual regurgitation grades over time was estimated by averaging resulting patient-specific profiles. A multiphase nonlinear mixed-effects regression model was used to estimate the temporal trend of continuous postoperative mean gradients and left ventricular ejection fraction.[24]

Time-related analyses. Survival and freedom from valve reoperation were estimated nonparametrically by the Kaplan–Meier method and parametrically by a multiphase hazard method.[25] To visualize the relation of calcium score to mortality without model assumptions in the subgroups of matched patients with available calcium scores, we performed random forests for survival (randomForestsSRC in R).[26] Missing data were imputed "on-the-fly" as a part of growing the forest object.[27] Partial-dependency plots were developed to describe the risk-adjusted relationship between calcium scores and mortality, integrating out the effect of all other covariates.[28]

RESULTS

Entire Commando Group

Procedural morbidity and operative mortality. Two patients (1.6%) experienced a permanent stroke, 9 (7%) required reoperation for bleeding, 15 (13%) developed

TABLE 3. Hospital morbidity and operative mortality among full and matched cohorts of patients undergoing Commando procedures and standard double-valve replacement

Outcome	Full cohort Commando (n = 129) n*	Full cohort Commando No. (%) or 15th/50th/85th percentiles	Matched Commando (n = 109) n*	Matched Commando No. (%) or 15th/50th/85th percentiles	Matched DVR (n = 109) n*	Matched DVR No. (%) or 15th/50th/85th percentiles	*P*
Operative mortality	129	14 (11)	109	12 (11)	109	8 (7.3)	.35
Stroke	129	2 (16)	109	1 (0.92)	109	2 (1.8)	>.9
Prolonged ventilation (>24 h)	129	45 (35)	109	37 (34)	109	31 (28)	.38
New requirement for dialysis	120	15 (13)	101	13 (13)	98	8 (8.2)	.28
Deep sternal wound infection	128	0 (0)	108	0 (0)	108	1 (0.93)	>.9
Septicemia	128	3 (2.3)	108	3 (2.8)	109	2 (1.8)	.68
Reoperation for bleeding or tamponade	129	9 (7.0)	109	9 (8.3)	108	5 (4.6)	.28
Blood product transfusion	129	116 (90)	109	98 (90)	109	97 (89)	.83
New postoperative atrial fibrillation	86	44 (51)	72	38 (53)	64	38 (59)	.44
ICU length of stay (h)	129	50/136/340	109	50/122/366	109	29/117/283	.04
Postoperative length of stay (d)	129	7/13/27	109	7/13/28	109	7/10/23	.17

DVR, Double-valve replacement; *ICU*, Intensive care unit. *Patients with data available.

new postoperative renal failure requiring dialysis, and 44 (51%) had postoperative atrial fibrillation (Table 3). Median duration of intensive care unit stay was 136 hours, and postoperative length of stay was 13 days. There were 14 (11%) operative deaths.

Longitudinal postoperative trends. At 4 years postoperatively, 92% had no aortic valve regurgitation and 91% no mitral regurgitation, 2.7% had moderate or more aortic valve regurgitation (Figure 1, *A*), and 1.6% had moderate or more mitral regurgitation (Figure 1, *B*). Mean aortic valve and mitral valve gradients were 9.2 mm Hg and 6.2 mm Hg, respectively (Figure 1, *C* and *D*). Left ventricular ejection fraction was 58% (Figure 2, *E*).

Time-related reoperation and mortality. Four patients underwent aortic or mitral valve reoperation postoperatively (Figure 3, *A*). Of these, 1 with severe aortic regurgitation underwent transcatheter aortic valve replacement. Patient 2 developed aortic and mitral valve regurgitation from breakdown of the intervalvular fibrosa patch (CorMatrix ECM, CorMatrix Cardiovascular) and underwent a repeat Commando procedure. Patient 3 presented with prosthetic mitral valve endocarditis and severe mitral stenosis and regurgitation and underwent re-replacement of the mitral valve. Patient 4 presented with active endocarditis involving a bovine pericardial patch in the ascending aorta and underwent a repeat Commando procedure. Freedom from reoperation was 99.8% at 1 year, 98.8% at 2 years, and 88% at 5 years.

Survival at 30 days and 1, 2, and 5 years was 92%, 78%, 72%, and 54%, respectively (Figure 3, *B*). Stratifying by presence of chest radiation or not, 5-year survival after a Commando procedure was 60% and 59%, respectively (Figure E3).

Commando and Standard Double-Valve Replacement

Patients undergoing a Commando procedure referenced to standard DVR were younger (62 ± 12 years vs 68 ± 12 years) and more likely female (60% vs 52%) (Table 1, Figure E2, *B*). They had less mitral regurgitation (63% vs 84%) and atrial fibrillation (31% vs 52%), but more aortic stenosis (75% vs 64%), larger aortic valve implant size (24 ± 2.3 vs 23 ± 2.3 mm), and smaller mitral valve implant size (28 ± 2.4 vs 29 ± 2.5 mm).

In achieving balance between these groups, the resulting subgroups had essentially the same preoperative characteristics as the Commando group. Thus, this subset of cases is different from that of typical patients undergoing standard DVR (Tables 1 and E1, Figure E2, *B*).

Outcomes of Matched Commando and Double-Valve Replacement Groups

Calcium score and long-term survival. Median mitral valve Agatston score was 2540 HU in the matched Commando group and 2190 HU in the DVR group ($P = .8$) (Table E3). Median total, aortic, and intervalvular fibrosa Agatston scores in the Commando and DVR groups were 6140 versus 2680 HU ($P = .03$), 1060 HU versus 575 HU ($P = .03$), and 928 versus 98 HU ($P < .0001$), respectively. Higher intervalvular fibrosa calcium score was not associated with death in the Commando group but was associated with worse survival in the DVR group (Figure E4). This was not the case for aortic valve (Figure E5) or mitral valve calcium score (Figure E6), which showed little association with mortality in either group.

Implanted valve label sizes. Mean implanted aortic valve label size was 24 ± 2.4 mm and 22 ± 2.2 mm ($P = .0008$) in the Commando and DVR groups, respectively (Table E4). Mean implanted mitral valve size was 28 ± 2.3 mm and 29 ± 2.7 mm, $P = .39$, respectively, in these groups.

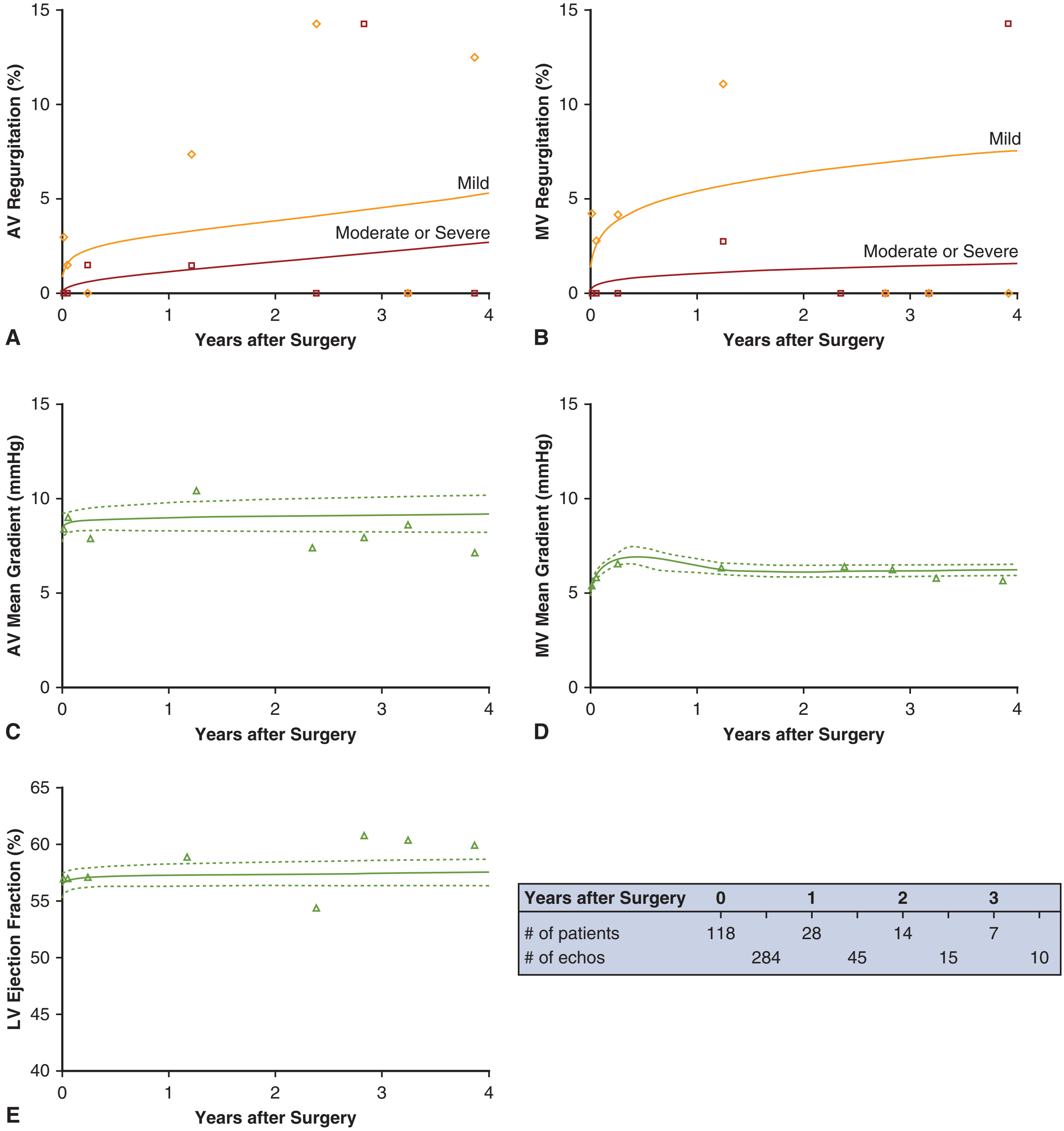
Operative details and in-hospital outcomes. Median myocardial ischemic time in the Commando and DVR groups was 144 and 152 minutes, respectively ($P = .51$; Table E4). Median cardiopulmonary bypass time was 192 and 178 minutes in these groups ($P = .09$).

Hospital outcomes. After Commando and DVR, occurrence of stroke, deep sternal wound infection, sepsis, atrial fibrillation, reoperation for bleeding, postoperative acute renal failure requiring dialysis, and respiratory failure requiring prolonged ventilation was similar (Table 3). Operative mortality was 11% after Commando procedures and 7.3% after DVR ($P = .35$). Patients had longer intensive care unit stays after Commando procedures (median 122 vs 117 hours).

Longitudinal echocardiographic trends. At 4 years postoperatively, aortic regurgitation was moderate or greater in 1.1% of the Commando group and 0.86% of the DVR group ($P = .65$; Figure 2, *A*), and mitral regurgitation was moderate or greater in 1.5% of the Commando group and 0.2% of the DVR group ($P = .009$; Figure 2, *B*). Mean aortic valve gradient was 9.4 mm Hg in the Commando group and 11 mm Hg in the DVR group ($P = .04$; Figure 2, *C*), and mean mitral valve gradient was 6.5 mm Hg in the Commando group and 6.4 mm Hg in the DVR group ($P > .3$; Figure 2, *D*). Left ventricular ejection fraction was 57% in both groups ($P = .89$; Figure 2, *E*).

Time-related reoperation and mortality. Three of the 4 reoperations (patients 1, 3, and 4, described previously) in the Commando group were in matched patients. Freedom from reoperation at 5 years was 87% in the Commando group and 100% in the DVR group (P [log-rank] $= .04$; Figure 4, *A*).

To the end of follow-up, 45 patients died in the Commando group and 31 died in the DVR group. Although we could not ascertain mode or cause of death in nearly half of each group, they were generally similar (Table E5).



Years after Surgery	0		1		2		3	
# of patients	118		28		14		7	
# of echos		284		45		15		10

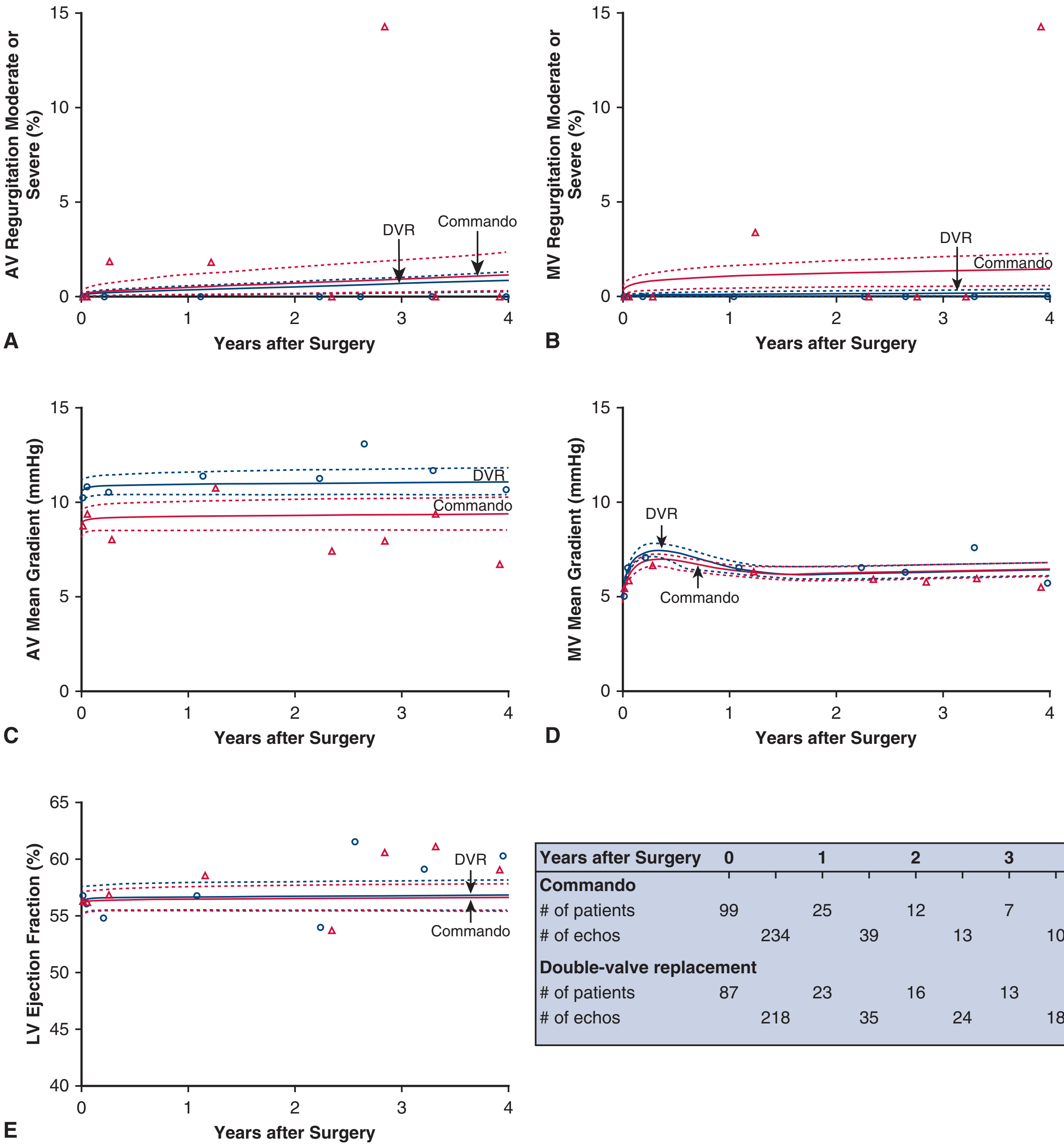
FIGURE 1. Longitudinal echocardiographic outcomes after Commando procedure. *Solid lines* are parametric estimates enclosed within dashed 68% confidence bands (equivalent to 1 standard error). Symbols represent grouped data without regard to repeated measurements to provide crude verification of model fit. Follow-up data for patients and echocardiograms are shown in table: left-hand numbers = patients remaining across follow-up years; right-hand numbers = follow-up echocardiograms available within each yearly interval. A, Postoperative prevalence of each aortic regurgitation grade. B, Postoperative prevalence of each mitral regurgitation grade. C, Temporal trend of postoperative aortic valve mean gradient. D, Temporal trend of postoperative mitral valve mean gradient. E, Temporal trend of postoperative ejection fraction. *AV*, Aortic valve; *MV*, mitral valve; *LV*, left ventricular.

Survival at 30 days and 1, 3, and 5 years after Commando procedures was 92%, 78%, 66%, and 54%, respectively, and 95%, 86%, 76%, and 67% after DVR, respectively (P = .33; Figure 4, *B*).

DISCUSSION

Principal Findings

The Commando procedure performed for noninfective pathology was primarily for destruction of the intervalvular



Years after Surgery	0		1		2		3	
Commando								
# of patients	99		25		12		7	
# of echos		234		39		13		10
Double-valve replacement								
# of patients	87		23		16		13	
# of echos		218		35		24		18

FIGURE 2. Longitudinal echocardiographic outcomes after Commando procedure and standard DVR in matched cohorts. *Solid lines* are parametric estimates enclosed within dashed 68% confidence bands (equivalent to 1 standard error). Symbols represent grouped data without regard to repeated measurements to provide crude verification of model fit. Follow-up data for patients and echocardiograms are shown in table: left-hand numbers = patients remaining across follow-up years; right-hand numbers = follow-up echocardiograms available within each yearly interval. A, Postoperative prevalence of moderate or severe aortic regurgitation. B, Postoperative prevalence of moderate or severe mitral regurgitation. C, Temporal trend of postoperative aortic valve mean gradient. D, Temporal trend of postoperative mitral valve mean gradient. E, Temporal trend of postoperative ejection fraction. *AV*, Aortic valve; *DVR*, double-valve replacement; *MV*, mitral valve; *LV*, left ventricular.

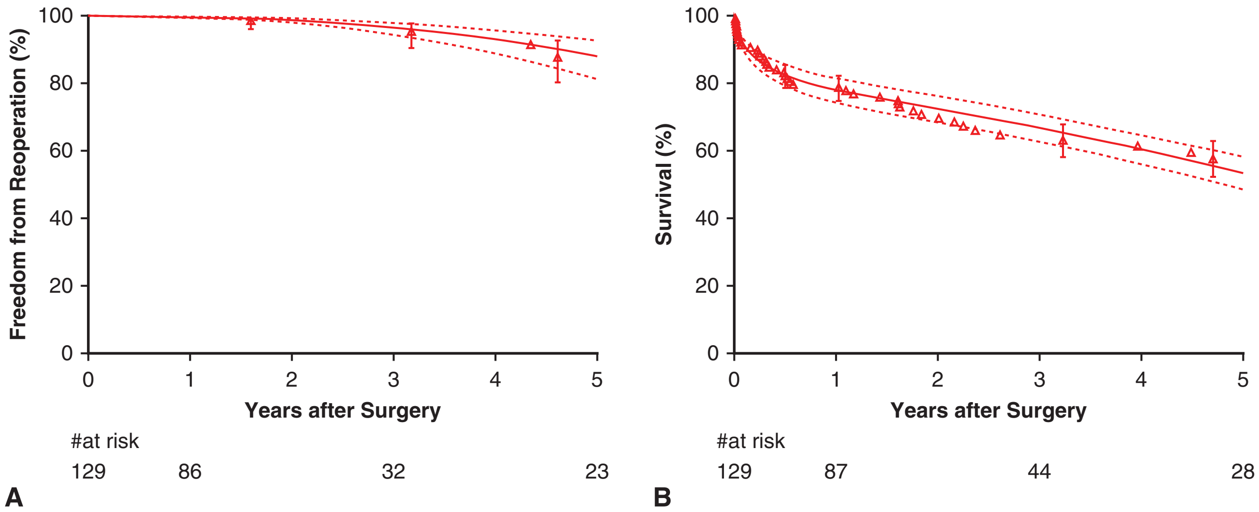


FIGURE 3. Time-related outcomes after Commando procedure. *Solid lines* represent parametric estimates enclosed within dashed 68% confidence bands equivalent to 1 standard error. Each symbol represents a Kaplan–Meier estimate of the event, and vertical bars are 68% confidence limits. Numbers below horizontal axes represent patients remaining at risk. A, Aortic valve or mitral valve reoperation. B, Survival.

fibrosa from calcification alone, with or without radiation heart disease, and occasionally for other situations, such as previous heart valve surgery with destruction of the intervalvular fibrosa. Characteristics of such patients are considerably different from those of patients undergoing standard DVR without intervalvular fibrosa reconstruction. For patients undergoing a Commando procedure referenced to a subgroup of patients undergoing standard DVR balanced for comorbidities, short-term outcomes were similar. Intermediate-term outcomes, primarily survival, were less favorable after Commando procedures than after DVR, perhaps related to their unique pathologies, such as radiation heart disease.

Replacing Both the Aortic and Mitral Valves

Standard DVR has been associated with hospital mortality of 5 to 15%.[29-32] Both anterior and posterior mitral anular calcification present challenges to mitral valve

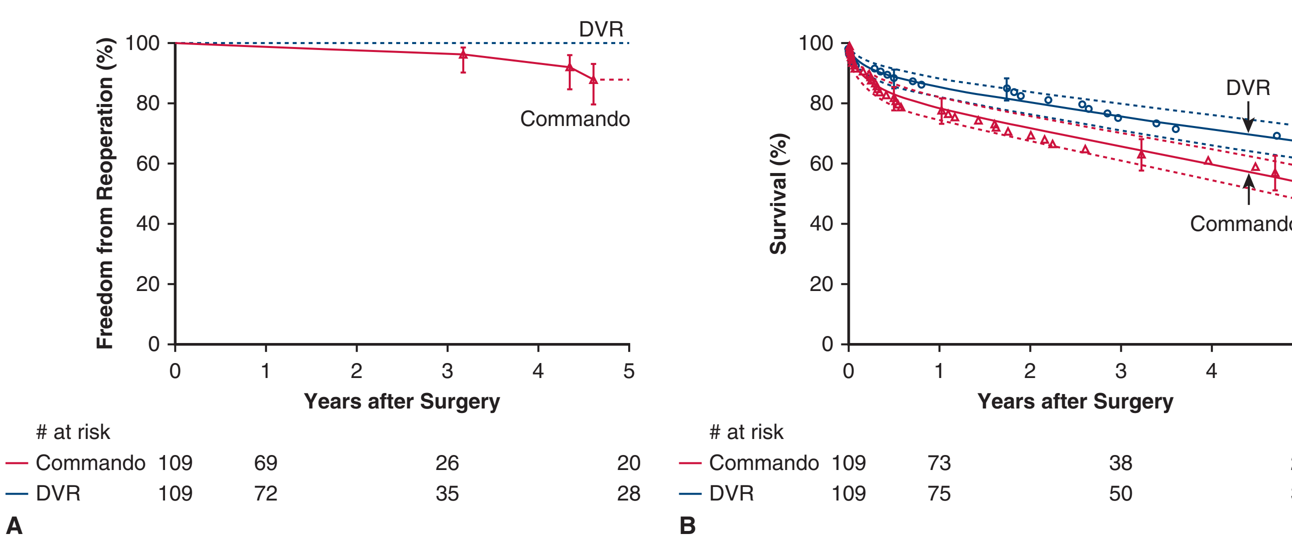


FIGURE 4. Time-related outcomes after Commando procedure and standard DVR in matched cohorts. Each symbol represents a Kaplan–Meier estimate of the event, and vertical bars are 68% confidence limits equivalent to ±1 standard error. Numbers below horizontal axis represent patients remaining at risk. A, Aortic valve or mitral valve reoperation. B, Survival. *Solid lines* are parametric estimates enclosed within dashed 68% confidence bands (equivalent to 1 standard error). *DVR*, Double-valve replacement.

implant, and the combination of a small mitral anulus with anterior mitral anular calcification affecting the entire intervalvular fibrosa is common, particularly in radiation-associated cardiac disease.

The Commando procedure for this pathology provides a means to avoid placing anular sutures through intervalvular fibrosa calcium and facilitates implanting larger valves.[8] Indeed, the Commando procedure, via patch enlargement of the anterior mitral anulus, is the only means of implanting a larger mitral valve than is possible with thorough debridement alone. Given the extensive reconstruction and challenging geometry, the Commando procedure has been considered a complex operation with high operative mortality ranging from 7% to 28% in prior series.[6,33] However, few studies have addressed whether procedural risk may be lower in noninfective endocarditis settings. In this regard, David and colleagues[7] analyzed 182 patients who underwent a Commando procedure (only 13% for endocarditis), with an operative mortality of 13% and 1-, 5-, and 10-year survivals of 82%, 69%, and 51%, respectively. In our study, operative mortality was 11% and 5-year survival was 53%.

We did not find that reconstruction of the intervalvular fibrosa incremented cardiopulmonary bypass time above that of our reference subgroup of standard DVRs, nor did it increment risk of major hospital morbidity. We had more reoperations over the 5 years after the Commando procedure, 1 related in retrospect to poor choice of patch material (CorMatrix). These reoperations reflect the finding that postoperative mitral regurgitation occurred more frequently after Commando procedures than after standard DVR.

Mitral Anular Calcification

During the last decade, importance of mitral anular calcification–related mitral valve dysfunction has gained attention.[11,12,34] It is an increasing cause of mitral valve disease in older western populations and is associated with poor prognosis.[12] Recent nuclear imaging studies also suggest that patients with mitral anular calcification have higher local calcific and inflammatory activities, which are associated with disease progression.[35] Quantifying and grading this calcification using echocardiography and cardiac CT are of increasing importance.[11,12,34] Thus, a thorough assessment of surgical risk in such patients is essential for optimizing preoperative therapy and surgical results.[11] In evaluating the effect on survival of calcium score in our patients, burden of calcium did not have a negative association with survival after Commando operations; however, the intervalvular fibrosa calcium score was associated with lower survival among patients who underwent standard DVR without replacing the intervalvular fibrosa. We believe that a Commando procedure is a better way of dealing with a severely calcified intervalvular fibrosa and find that it provides better exposure for posterior debridement of calcium.

Indications for Commando Procedure

The Commando procedures in this study, which excluded those for infective endocarditis, were performed when DVR alone was not possible, such as when the intervalvular fibrosa was heavily calcified and destroyed after debridement or had been used up by repeated previous mitral or double-valve operations. For some patients, declared inoperable before referral, a Commando procedure was a new option. In patients with poor quality and fragility of tissue from radiation-induced heart disease, and in those with small hearts, intervalvular fibrosa reconstruction may reduce the risk of periprosthetic leakage. The Commando procedure also provides the surgeon with greater visual exposure than standard DVR, explaining the small difference in cardiopulmonary bypass times.

For patients with a small mitral anulus size, the Commando procedure provides a way to accommodate a standard-sized mitral prosthesis. It is true that in our study there was little difference in mitral valve size between the Commando and the reference DVR groups. However, we do not know preoperative anular sizes, which are difficult to measure in the presence of extensive calcification.

With careful preoperative evaluation, informed patient selection, and better understanding of the role of calcification on long-term outcomes, the Commando procedure has a niche among available strategies to address double-valve pathologies. These, in particular, include mitral anular calcification involving the intervalvular fibrosa, such as that associated with radiation heart disease.

Limitations

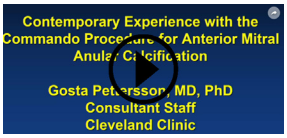
This is an observational clinical study at a single institution, which limits generalizability of our results but provides greater details from patient records. Patients undergoing a Commando procedure have different characteristics (including pathologies) than those undergoing standard DVR, limiting outcome comparisons because of lack of exchangeability. Thus, our objective, particularly in defining a reference group, was not to determine if results after the Commando procedure were better or worse than after standard DVRs. Rather, we wanted to place the results of the Commando procedure in the context of a subgroup of patients undergoing standard DVRs with a similar high-risk demographic and comorbidity profile to see if there were important deviations from that group. In constructing a reference group of standard DVRs using a balancing score, although some standardized differences were in the ±10% region of good matches, the resulting groups were similar in demographics and comorbidities but substantially different from typical patients undergoing standard DVR. The short median follow-up time reflects recent increase in use of the Commando procedure. This does not detract from actuarial data from earlier in the series that provide intermediate-term estimates. Nevertheless, those intermediate-term actuarial estimates are based on follow-up of the earlier cases in the series and may be subject to temporal trends in unmeasured operative and postoperative variables. Comparisons between balanced groups should be understood as being against a reference group, not a directly comparable group, and the number of events observed in matched groups makes tests of differences underpowered.

CONCLUSIONS

The Commando procedure with reconstruction of the intervalvular fibrosa destroyed by radiation heart disease, mitral anular calcification, or previous operations has demonstrated outcomes similar to standard DVR in similarly high-risk patients. More experience and evaluation of long-term outcomes are required to refine indications and patient selection and to aid decision-making on applying the Commando procedure.

Webcast

You can watch a Webcast of this AATS meeting presentation by going to: https://www.aats.org/resources/contemporary-experience-with-the-commando-procedure-for-anterior-mitral-anular-calcification.



Conflict of Interest Statement

The authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

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Key Words: double-valve replacement, intervalvular fibrosa reconstruction, radiation-associated cardiac disease

APPENDIX E1: VARIABLES CONSIDERED IN ANALYSIS (ASTERISKS DENOTE VARIABLES INCLUDED IN BALANCING MODEL)

Demographics

Female,* white race,* black race,* age (y),* height (cm), weight (kg), body surface area (m^2), body mass index (kg/m^2)*

Symptoms

New York Heart Association functional class (I-IV)*

Valve Pathology and Pathophysiology

Aortic valve. Native valve disease,* regurgitation, regurgitation grade,* stenosis,* mean gradient (mm Hg),* peak gradient (mm Hg), degeneration pathology*

Mitral valve. Native valve disease,* regurgitation, regurgitation grade,* stenosis,* mean gradient (mm Hg),* peak gradient (mm Hg), degeneration pathology*

Tricuspid valve. Regurgitation, regurgitation grade*

Pulmonary valve. Regurgitation*

Cardiac Comorbidity

Prior myocardial infarction,* number of diseased coronary systems*

Left ventricle. Ejection fraction (%),* fractional shortening (%), inner diameter in diastole (cm), inner diameter in systole (cm), end-diastolic volume (mL), end-systolic volume (mL), end-diastolic volume index (mL/m^2),* end-systolic volume index (mL/m^2),* relative wall thickness (cm),* intraventricular septal thickness (cm), posterior wall thickness (cm),* mass (g), mass index (g/m^2)*

Right ventricle. Systolic pressure (mm Hg)*

Other. Prior cardiac surgery,* atrial fibrillation or flutter,* complete heart block/pacer,* heart failure,* mid-ascending aorta diameter (cm)*

Noncardiac Comorbidity

Peripheral artery disease,* hypertension,* pharmacologically treated diabetes,* insulin-treated diabetes,* non–insulin-treated diabetes,* chronic obstructive pulmonary disease,* history of smoking,* renal dialysis,* prior stroke,* bilirubin (mg/dL),* creatinine (mg/dL),* blood urea nitrogen (mg/dL),* hematocrit (%)*

Concomitant Procedures

Coronary artery bypass grafting,* tricuspid valve repair,* aortic arch, ascending aorta, or root procedure,* ablation procedure for atrial fibrillation,* septal myectomy*

Experience

Date of surgery*

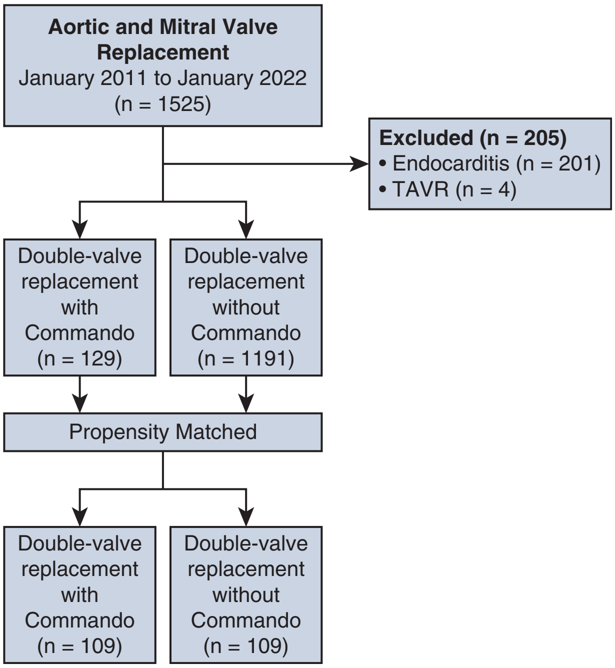

FIGURE E1. CONSORT-style diagram of patients undergoing simultaneous aortic and mitral valve replacement with or without a Commando procedure. *TAVR*, Transcatheter aortic valve replacement.

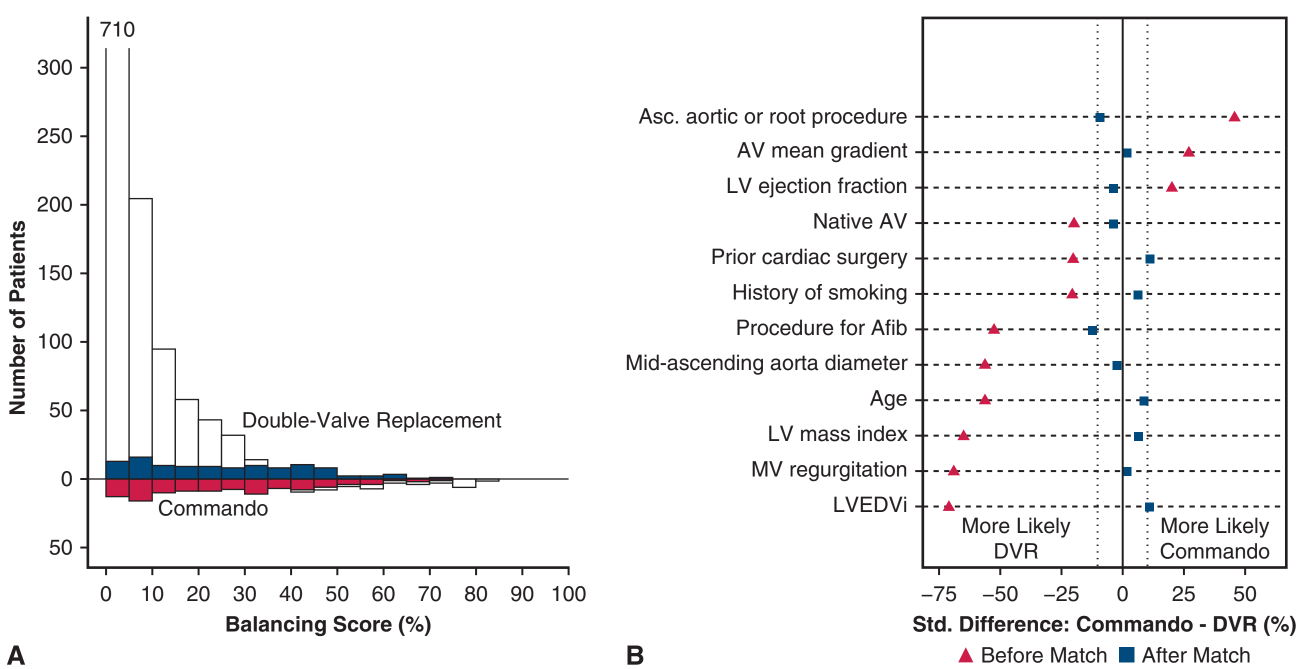

FIGURE E2. Quality of balancing score–based matching for Commando and standard DVR. A, Mirrored histogram of distribution of balancing scores before and after matching. Shaded areas represent matched patients. B, Standardized mean differences of selected variables before and after matching. *Vertical dashed lines* at −10% and +10% indicate boundaries of describing matching. *Red triangles* represent standardized mean differences before matching, with positive value indicating variables more common in the Commando group and negative value indicating variables more common in the DVR group. *AV*, Aortic valve; *LV*, left ventricular; *MV*, mitral valve; *LVEDVi*, left ventricular end-diastolic volume index; *DVR*, double-valve replacement; *Std.*, standardized.

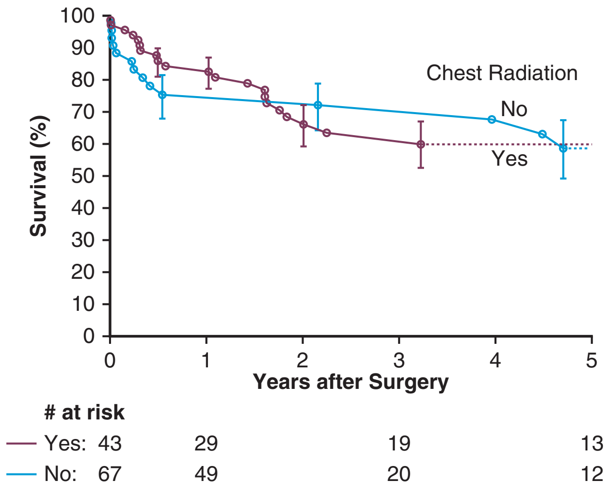

FIGURE E3. Survival after Commando procedure stratified by reason for surgery. Each symbol represents a death; vertical bars represent 68% confidence limits equivalent to ±1 standard error. *Mauve line and circles* represent Commando procedures for mitral anular calcification with radiation-associated heart disease. *Cyan line and circles* represent Commando procedures for mitral anular calcification without radiation-associated heart disease.

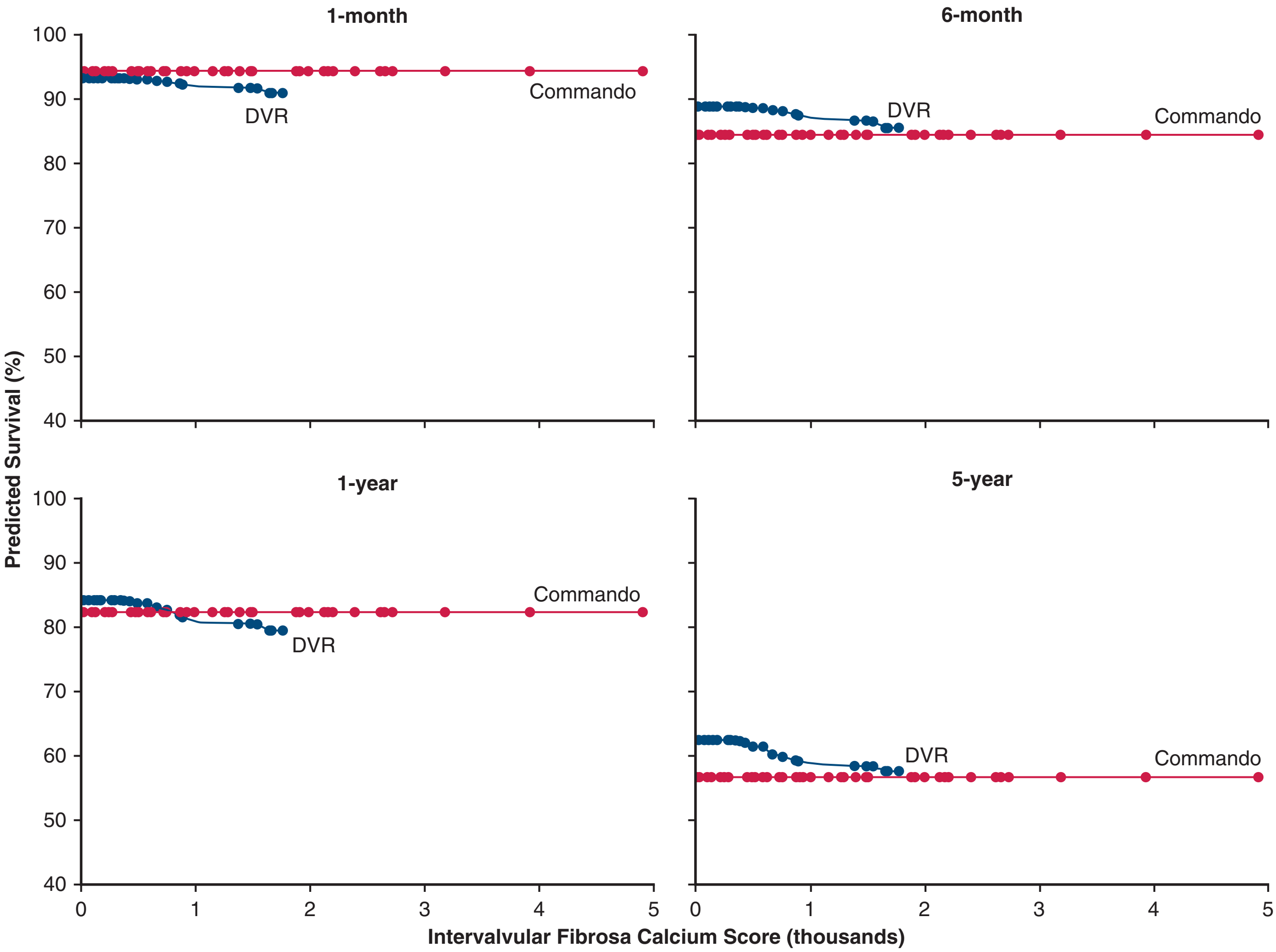

FIGURE E4. Risk-adjusted association between intervalvular fibrosa calcium score and probability of death. Symbols are risk-adjusted predicted 1-month, 6-month, 1-year, and 5-year survival stratified by Commando procedure (*red*) versus standard DVR (*blue*) in matched cohorts. *Solid lines* are smoothed Loess lines of the symbols. *DVR*, Double-valve replacement.

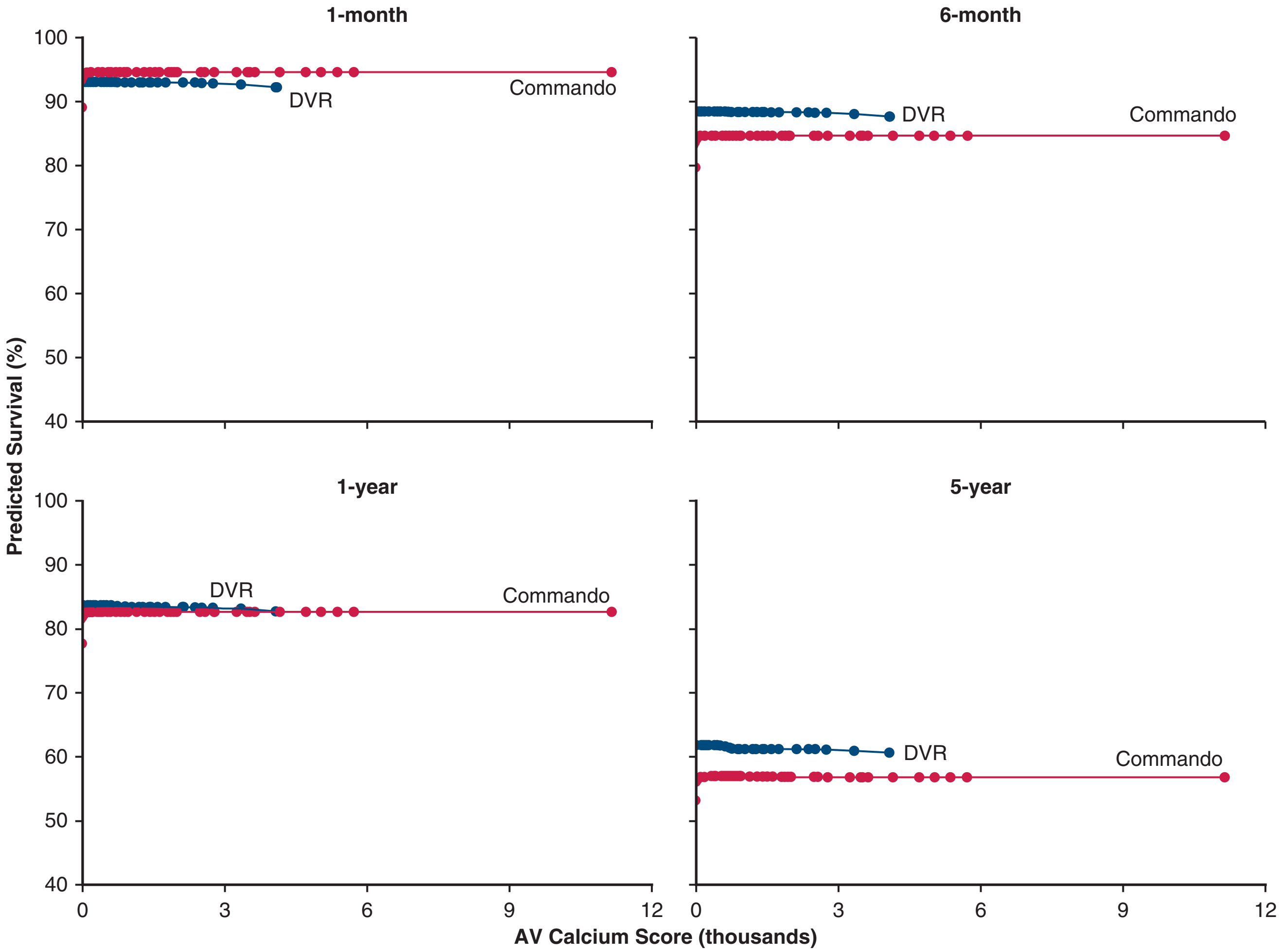

FIGURE E5. Risk-adjusted association between aortic valve calcium score and probability of death. Symbols are risk-adjusted predicted 1-month, 6-month, 1-year, and 5-year survival stratified by Commando procedure (*red*) versus standard DVR (*blue*) in matched cohorts. *Solid lines* are smoothed Loess lines of the symbols. *DVR*, Double-valve replacement; *AV*, aortic valve.

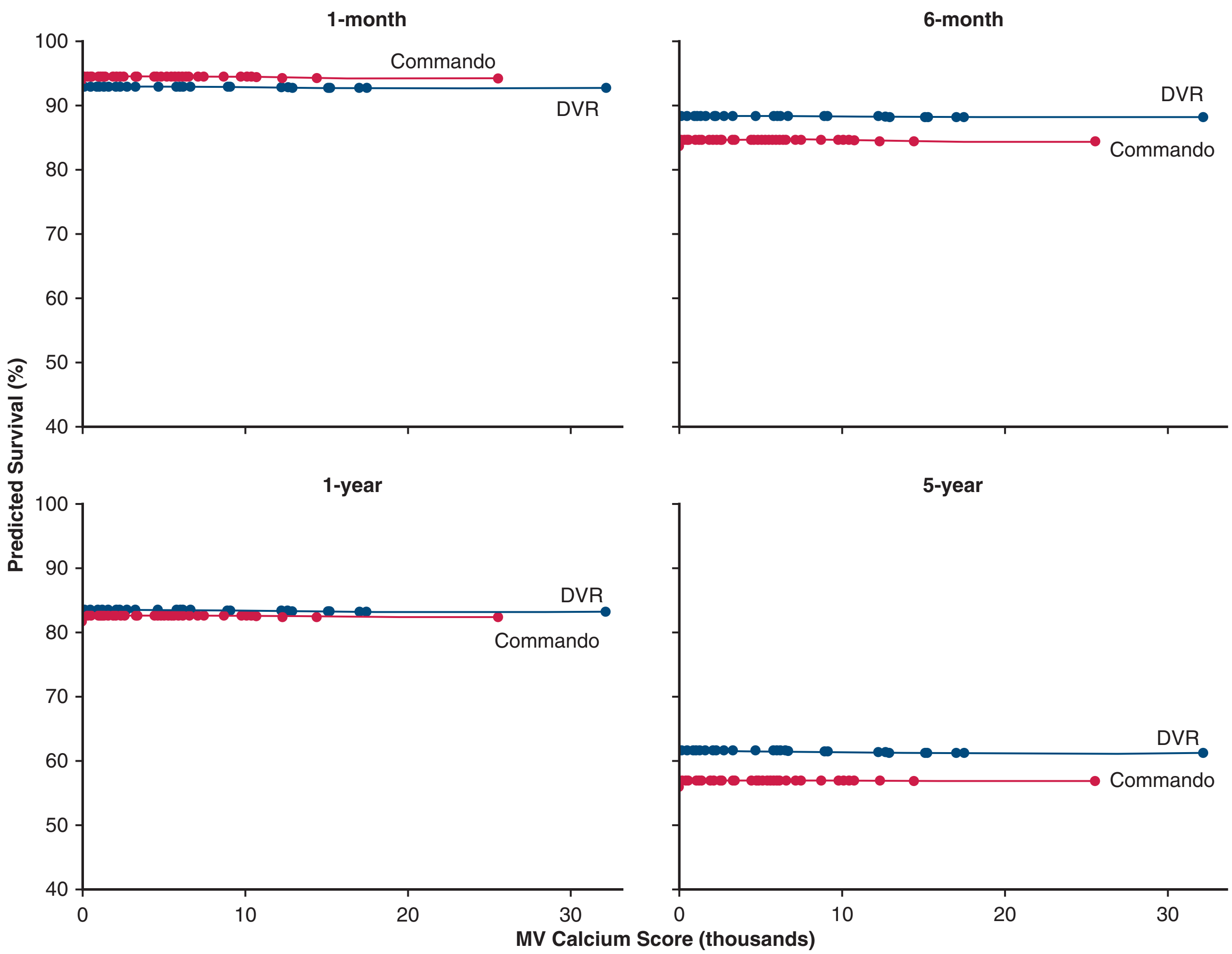

FIGURE E6. Risk-adjusted association between mitral valve calcium score and probability of death. Symbols are risk-adjusted predicted 1-month, 6-month, 1-year, and 5-year survival stratified by Commando procedure (*red*) versus standard DVR (*blue*) in matched cohorts. *Solid lines* are smoothed Loess lines of the symbols. *DVR*, Double-valve replacement; *MV*, mitral valve.

TABLE E1. Characteristics of aortic and mitral valve disease in full and matched cohorts of patients undergoing Commando procedure or standard double-valve replacement

	Full cohorts								Matched cohorts							
	Commando (n = 129)				DVR (n = 1191)				Commando (n = 109)				DVR (n = 109)			
	Aortic valve disease		Mitral valve disease		Aortic valve disease		Mitral valve disease		Aortic valve disease		Mitral valve disease		Aortic valve disease		Mitral valve disease	
Characteristic	n*	No. (%)	n*	No. (%)	n*	No. (%)	n*	No. (%)	n*	No. (%)	n*	No. (%)	n*	No. (%)	n*	No. (%)
Native valve	129	80 (62)	129	106 (82)	1191	849 (71)	1191	967 (81)	109	65 (60)	109	89 (82)	109	67 (61)	109	91 (83)
Prior repair	128	4 (3.1)	128	10 (7.8)	1105	27 (2.4)	1105	180 (16)	108	4 (3.7)	108	9 (8.3)	107	2 (1.9)	107	9 (8.4)
Prior replacement	128	48 (38)	128	21 (16)	1105	321 (29)	1105	160 (14)	108	43 (40)	108	19 (18)	107	40 (37)	107	15 (14)
AR grade	128		128		1189		1186		108		108		109		109	
None		44 (34)		47 (37)		395 (33)		185 (16)		39 (36)		38 (35)		44 (40)		34 (31)
Mild		28 (22)		32 (25)		283 (24)		218 (18)		25 (23)		26 (24)		27 (25)		32 (30)
Moderate		37 (29)		29 (23)		325 (27)		294 (25)		28 (26)		26 (24)		25 (23)		28 (26)
Severe		19 (15)		20 (16)		186 (16)		489 (41)		16 (15)		19 (17)		13 (12)		14 (13)
Mean gradient (mm Hg)†	122	33 ± 18	117	10 ± 4.4	1005	28 ± 18	899	9.3 ± 4.8	102	32 ± 18	98	10 ± 4.5	101	32 ± 20	99	11 ± 4.6

DVR, Double-valve replacement; *AR*, aortic regurgitation. *Patients with data available. †Mean ± SD.

TABLE E2. Patient variables associated with Commando procedure versus standard double-valve replacement (C-statistic = .80)

Variable	Estimate ± SE	*P*	Reliability (%)*
Higher likelihood of Commando procedure			
Recent date of surgery†	0.26 ± 0.13	.047	57
History of COPD	0.55 ± 0.21	.01	62
Any root, ascending aorta, or arch procedure	0.77 ± 0.23	.0008	89
Higher likelihood of DVR			
Older age‡	0.50 ± 0.17	.0039	69
Greater LV mass index§	−0.75 ± 0.20	.0003	84
Severe mitral valve regurgitation	0.45 ± 0.09	<.0001	70
Prior cardiac surgery	1.17 ± 0.30	.0001	62
Smoking	0.50 ± 0.22	.021	88
Atrial fibrillation	1.19 ± 0.36	.0008	88
Native aortic valve	0.74 ± 0.32	.019	51

COPD, Chronic obstructive pulmonary disease; *DVR*, double-valve replacement; *LV*, left ventricular. *Percent of time factor appeared in 1000 bootstrap analyses and was retained with $P < .05$. †Log (interval from January 1, 2011 to date of surgery), natural logarithmic transformation. ‡$(\text{Age}/50)^2$, squared transformation. §(130/LV mass index), inverse transformation.

TABLE E3. Calcium scores of matched patients undergoing Commando procedure or double-valve replacement

	Commando (n = 109)		DVR (n = 109)		
Calcium score for	n*	15th/50th/85th percentiles	n*	15th/50th/85th percentiles	*P*
Mitral valve	56	83/2540/9200	47	0/2190/12,600	.8
Aortic valve	52	110/1060/3660	44	0/575/2190	.03
Intervalvular fibrosa	55	56/928/2530	44	0/98/1010	<.0001
Total calcium score	52	980/6140/12,700	45	34/2680/13,200	.03

DVR, Double-valve replacement. *Patients with data available.

TABLE E4. Intraoperative details of full and matched cohorts of patients undergoing Commando procedure or standard double-valve replacement

	Full cohort		Matched cohorts				
	Commando (n = 129)		Commando (n = 109)		DVR (n = 109)		
Outcome	n*	No. (%) or 15th/50th/85th percentiles	n*	No. (%) or 15th/50th/85th percentiles	n*	No. (%) or 15th/50th/85th percentiles	*P*
Aortic clamp time (min)	129	111/143/229	109	112/144/229	109	100/152/204	.51
Cardiopulmonary bypass time (min)	129	134/188/279	109	135/192/279	109	122/178/247	.09
Aortic valve prosthesis type							
Mechanical	129	31 (24)	109	27 (25)	109	39 (36)	.08
Bioprosthesis	129	96 (74)	109	80 (73)	109	66 (61)	.04
Allograft	129	2 (1.6)	109	2 (1.8)	109	4 (3.7)	.41
Aortic valve prosthesis size (17-29 mm)	120	21/23/27	102	21/23/27	101	21/23/25	.04
Mitral valve prosthesis type							
Mechanical	129	34 (26)	109	29 (27)	109	40 (37)	.11
Bioprosthesis	129	95 (74)	109	80 (73)	109	69 (63)	.11
Mitral valve prosthesis size (21-33 mm)	129	25/29/31	109	25/29/31	107	25/29/31	.52
Posterior debridement	129	75 (58)	109	64 (59)	109	42 (39)	.0029
Posterior anular patch	129	30 (23)	109	26 (24)	109	9 (8.3)	.0017
Tricuspid valve repair	129	34 (26)	109	28 (26)	109	23 (21)	.42
Coronary artery bypass grafting	129	38 (29)	109	31 (28)	109	28 (26)	.65
Ablation for atrial fibrillation	129	9 (7.0)	109	9 (8.3)	109	13 (12)	.37
Septal myectomy	127	6 (4.7)	109	6 (5.5)	109	7 (6.4)	.77
Any root, arch, or ascending aorta procedure	129	46 (36)	109	33 (30)	109	38 (35)	.47
Root procedure (yes/no)	129	17 (13)	109	13 (12)	109	22 (20)	.10
Ascending aorta procedure (yes/no)	129	14 (11)	109	9 (8.3)	109	14 (13)	.27
Aortic arch procedure (yes/no)	129	2 (1.6)	109	2 (1.8)	109	2 (1.8)	.99

DVR, Double-valve replacement. *Patients with data available.

TABLE E5. Modes or cause of death after Commando procedure and standard matched double-valve replacement

	Commando		Matched DVR	
Mode or cause	No. of deaths	Median interval to death (y)	No. of deaths	Median interval to death (y)
Cardiogenic shock	8	0.03	5	0.04
Acute respiratory failure	7	1.2	2	5.0
Multisystem organ failure	5	0.07	2	0.03
Sepsis	3	1.6	2	0.36
New endocarditis in postoperative period	3	0.52	0	—
Stroke	2	0.79	0	—
AV groove disruption	0	–	2	0
Metastatic cancer	1	4.0	3	3.0
Ischemic bowel	1	0.02	0	—
Unknown	23	2.3	15	1.9
Total	53		31	

DVR, Double-valve replacement; *AV*, aortic valve.