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Propensity-Matched Comparison of the Ross Procedure and Prosthetic Aortic Valve Replacement in Adults

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ABSTRACT

BACKGROUND There has recently been renewed interest in the Ross procedure in adults.

OBJECTIVES The goal of this study was to compare long-term outcomes after the Ross procedure vs biological and mechanical aortic valve replacement (AVR) in adults (aged 18-50 years) undergoing aortic valve surgery.

METHODS Mandatory California and New York databases were queried between 1997 and 2014. Exclusion criteria included: ≥1 concomitant procedure, reoperations, infective endocarditis, intravenous drug use, hemodialysis, and out-of-state residency. Propensity matching (1:1:1) was used, resulting in 434 patients per group. The primary endpoint was all-cause mortality. Secondary endpoints were stroke, major bleeding, reoperation, and endocarditis. Median follow-up was 12.5 years (IQR: 9.3-15.7 years).

RESULTS At 15 years, actuarial survival after the Ross procedure was 93.1% (95% CI: 89.1%-95.7%), similar to that of the age-, sex-, and race-matched U.S. general population. It was significantly lower after biological AVR (HR: 0.42; 95% CI: 0.23-0.075; $P = 0.003$) and mechanical AVR (HR: 0.45; 95% CI: 0.26-0.79; $P = 0.006$). At 15 years, the Ross procedure was associated with a lower cumulative risk of reintervention ($P = 0.008$) and endocarditis ($P = 0.01$) than biological AVR. In contrast, at 15 years, the Ross procedure was associated with a higher cumulative incidence of reoperation ($P < 0.001$) but lower risks of stroke ($P = 0.03$) and major bleeding ($P = 0.016$) than mechanical AVR. Thirty-day mortality after valve-related complications was lowest after a reintervention.

CONCLUSIONS In young adults, the Ross procedure is associated with better long-term survival and freedom from valve-related complications compared with prosthetic AVR. This confirms the notion that a living valve substitute in the aortic position translates into improved clinically relevant outcomes. (J Am Coll Cardiol 2022;79:805-815) © 2022 by the American College of Cardiology Foundation.

The ideal substitute in young adults requiring aortic valve replacement (AVR) remains a matter of debate. Although bioprostheses are the favored option for older patients, their use in younger patients is associated with higher rates of structural valve degeneration and reoperation. In contrast, mechanical valves provide a more durable option but require a lifetime of anticoagulation and, in some cases, lifestyle modifications. In recent years, the Ross procedure has emerged as an alternative to prosthetic AVR, with data suggesting it is associated with restored long-term survival compared to the general population.[1,2] However, most studies are single-center (and often single-surgeon) series from experienced centers, limiting their external validity. In addition, there is currently a paucity of data

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ABBREVIATIONS AND ACRONYMS

AVR = aortic valve replacement

ICD-9-CM = International Classification of Disease-9th Revision-Clinical Modification

comparing the Ross procedure to conventional AVR, particularly biological AVR, which has become more widely used in the last decade across a spectrum of ages because of lifestyle considerations and the possibility of less invasive procedures as follow-up interventions.

SEE PAGE 816

Current guidelines suggest that the choice of prosthesis should be a shared decision-making process that involves patient preferences and values.[3] In younger patients, in addition to the more immediate concerns of surgical access and operative risk, long-term clinically relevant outcomes should be a key part of this conversation. To this end, more data are needed to provide patients with better information and to allow them to make true value-based decisions. The aim of the current study therefore was to provide a comprehensive comparison of different surgical options using statewide administrative data to mitigate surgeon or center effects. We directly examined long-term survival, reoperation, stroke, major bleeding, and endocarditis in young adults undergoing mechanical AVR, biological AVR, or a Ross procedure. To mitigate possible patient- or valve-related confounders, a propensity-matched analysis with strict exclusion criteria was applied. In addition, although in daily practice the Ross procedure is offered to patients >50 years of age, it is done more selectively, and part of that selection process cannot be measured with objective criteria (ie, "eyeballing"). As a result, we only included patients aged <50 years to reduce unmeasured patient-related factors that represent potential confounders and instead focused on the impact of prosthesis choice.

METHODS

STUDY DESIGN AND PATIENT POPULATION. This retrospective analysis included young adult patients aged 18 to 50 years who underwent primary AVR using either pulmonary autograft (Ross procedure) or prosthetic (biological or mechanical) valves in California and New York State between January 1, 1997, and December 31, 2014. We compared the long-term survival and risk of valve-related complications (stroke, major bleeding, reoperation, and acute endocarditis) according to the surgical procedure. Patients were identified by using the Office of Statewide Health Planning Development database in California and the Statewide Planning and Research Cooperative System in New York, both an all-payer, administrative database that prospectively collects data on every hospital discharge, ambulatory surgery, and emergency department visit in California and New York State, respectively. Unique patient identifiers were allocated to each encounter, allowing longitudinal analyses. Patients undergoing prosthetic AVR were identified by using International Classification of Disease-9th Revision-Clinical Modification (ICD-9-CM), procedure codes 35.21 (biological) and 35.22 (mechanical); patients undergoing the Ross procedure were identified by using the simultaneous use of ICD-9-CM code 35.21 (biological AVR including pulmonary autograft) and 35.25 (replacement of pulmonary valve with tissue graft including homograft) on the same procedure date.

Exclusion criteria included out-of-state residency and age <18 years or >50 years. We also excluded any of the following patient-related factors because of their potential impact on long-term outcomes: concomitant mitral and/or tricuspid valve surgery or coronary artery bypass grafting, end-stage renal disease, intravenous drug use, acute aortic dissection, infective endocarditis, any history of carcinoid disease, or Marfan syndrome (Supplemental Table 1). Baseline comorbidities were identified by using present-on-admissions diagnosis codes from the index hospitalization and all diagnoses from hospitalizations before the index hospitalization (Supplemental Table 2).

Validation of the use of combined ICD-9-CM coding for the Ross procedure was conducted by using patients' electronic medical records identified from the Mount Sinai Data Warehouse. Hospitalizations for the Ross procedure at Mount Sinai Medical Center (New York, New York, USA) from January 1, 2000, through December 31, 2014, were identified by key word search ("Ross procedure" or "Ross operation") and surgeons' case logs. We evaluated reliability of combined ICD-9-CM codes defined in this study for identification of the Ross procedure. The positive predictive value, sensitivity, and specificity of the combined ICD-9-CM codes for the Ross operation were 98% (95% CI: 94%-99%), 92% (95% CI: 86%-96%), and 99% (95% CI: 99%-99%), respectively. The ICD-9-CM codes for prosthetic aortic valves were well validated with high positive predictive values in this age group.[4]

The current study was approved by the Data Protection Review Board of the New York State Department of Health, the California Committee for the Protection of Human Subjects, and the Program for Protection of Human Subjects at the Icahn School of Medicine at Mount Sinai. The approval included a waiver of informed consent.

STUDY ENDPOINTS. The primary endpoint was all-cause mortality. Secondary endpoints were stroke, major bleeding, reoperation (including any reoperation on the pulmonary valve for the Ross procedure cohort), and acute endocarditis. Deaths were ascertained from the linked state's vital statistics death records, deceased discharge disposition at any subsequent in-hospital and emergency department and ambulatory surgery visits, and additionally from the Social Security Death Master File. Stroke was defined as a postoperative cerebrovascular accident during the index admission or a primary diagnosis of hemorrhagic or ischemic cerebrovascular event during any subsequent inpatient admission. This definition did not include transient ischemic attacks. Major bleeding events were those that required inpatient admission with a primary diagnosis of intracerebral hemorrhage, hemopericardium, cardiac tamponade, gastrointestinal hemorrhage, hematuria, hemarthrosis, hemoptysis, epistaxis, or ocular hemorrhage. Reoperation was defined as any operation involving the aortic and/or pulmonary valves. Any patient free from death, stroke, major bleeding, reoperation, or endocarditis was censored on December 31, 2015, which was the most recent follow-up date available for clinical events. Median follow-up time was 12.5 years (IQR: 9.3-15.7 years).

STATISTICAL ANALYSIS. Normally distributed continuous variables are reported as mean ± SD and compared with an analysis of variance. The other continuous variables are reported as median with IQR and compared with the Wilcoxon rank sum test. Categorical variables are expressed as proportions and compared with the chi-square test. The baseline differences between the groups were detected by using standardized differences.

To adjust for treatment selection bias, we conducted three-way 1:1:1 propensity score matching on 3 treatment groups using the generalized propensity score.[5] These propensity scores were calculated with a multinomial logistic regression model. Patients' baseline demographic characteristics and comorbidities (age, sex, race, history of hypertension, diabetes, congestive heart failure, chronic kidney disease, coronary artery disease, atrial fibrillation, peripheral vascular disease, chronic obstructive pulmonary disease, liver disease, cancer, cerebrovascular disease, coagulation disorders, and previous endocarditis), and admission year were included in the model as covariates. To further reduce the selection bias, we also included in the model institutional experience, defined by the annual AVR volume for any age group. Generalized propensity matching was conducted 1:1:1 with the wild bootstrap for variance estimation. Balance assessment after matching was measured by using the standard mean difference, and the absolute standard mean difference <10% indicated successful adjustment.

TABLE 1 Patient Characteristics After Propensity Matching for Patients Undergoing a Ross Procedure, Biological AVR, and Mechanical AVR

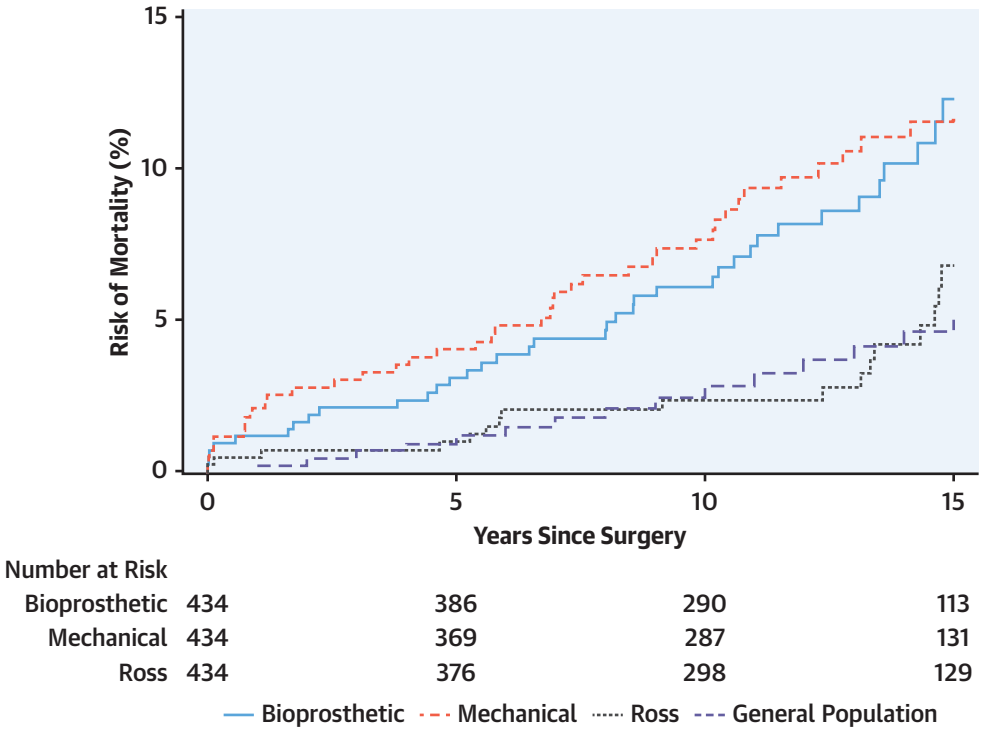
	Ross Procedure (n = 434)	Bioprosthetic AVR (n = 434)	Mechanical AVR (n = 434)
Age, y	35.9 ± 9.2	36.2 ± 9.4	36.7 ± 8.8
Sex	324 (75)	315 (73)	337 (78)
Race			
White	322 (74)	309 (71)	306 (71)
Black	21 (5)	15 (4)	24 (6)
Other	91 (21)	110 (25)	104 (24)
Hypertension	80 (18)	79 (18)	81 (19)
Atrial fibrillation	16 (4)	15 (4)	14 (3)
Congestive heart failure	65 (15)	65 (15)	62 (14)
Complicated DM	1 (0.2)	1 (0.2)	0 (0)
CKD (non-HD)	2 (0.5)	2 (0.5)	1 (0.2)
COPD	21 (5)	16 (4)	14 (3)
Liver disease	4 (1)	4 (1)	5 (1)
History of cancer	4 (1)	8 (2)	3 (1)
Mean AVR volumes	156 ± 93	157 ± 112	160 ± 117
NY residents	182 (42)	186 (43)	196 (45)
Median hospital LOS, d	5	5	6

Values are mean ± SD, n (%), or median.

AVR = aortic valve replacement; CKD = chronic kidney disease; COPD = chronic obstructive pulmonary disease; DM = diabetes mellitus; HD = hemodialysis; LOS = length of stay; NY = New York.

Survival curves of the primary endpoint of all-cause mortality were constructed with the Kaplan-Meier method. Cumulative incidence curves for the secondary endpoints were constructed with competing risk analysis, with death as a competing event, and compared with the Gray test. Marginal Cox models with a robust sandwich variance estimator were used to assess the difference in outcomes in the matched cohorts. HRs with the Ross procedure as a reference were calculated by fitting Cox proportional hazards regression models with each outcome as a dependent variable and the surgery type as a covariate. In each model, proportional hazard assumption was evaluated and, if violated, the interaction term between time-to-event and the surgery type were incorporated into the model, and HRs were calculated at different follow-up time points. Cumulative relative survival of patients who underwent the Ross procedure compared with the age-, sex-, and race-matched general population was calculated with 95% CIs. Normal population-expected survival was extracted from the Surveillance, Epidemiology, and End Results Program of the National Institutes of

FIGURE 1 Long-Term Cumulative Incidence of All-Cause Mortality Compared With the Matched U.S. General Population



At 15 years, the cumulative incidence of all-cause mortality is significantly lower after the Ross procedure **(gray)** compared with biological aortic valve replacement **(blue)** (HR: 0.42; $P = 0.003$) or mechanical aortic valve replacement **(red)** (HR: 0.45; $P = 0.006$). Survival after the Ross procedure is equivalent to that of the age-, sex-, and race-matched U.S. general population **(purple)**.

Health, which provides life tables for the U.S. population stratified according to year (currently 1970-2017), age (0-99 years), sex, and race.

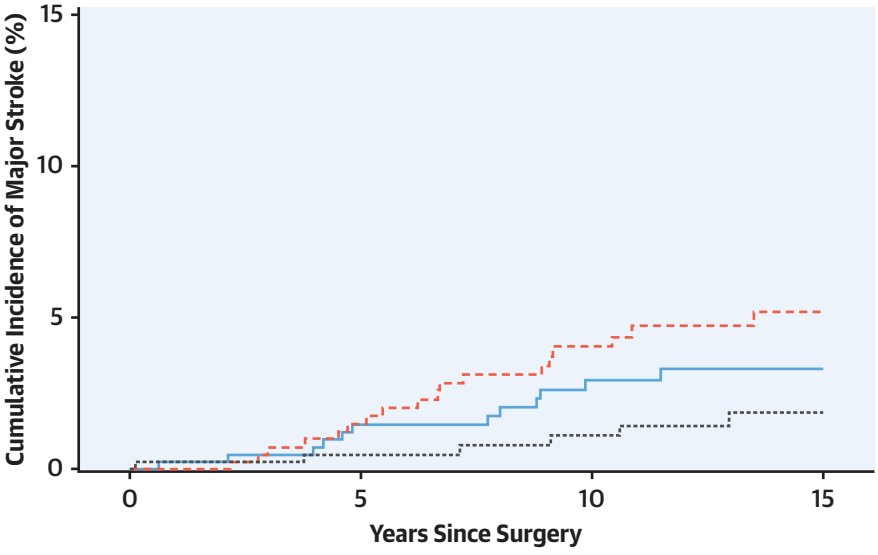
As a validation of the results of propensity matching, analyses were repeated including the entire cohort for all study endpoints using a conventional regression model (Supplemental Figures 1 to 5). All tests were 2-tailed, and an alpha-level of 0.05 was considered statistically significant. All statistical analyses were performed with SAS version 9.4 (SAS Institute, Inc).

RESULTS

STUDY POPULATION. A total of 16,402 patients aged 18 to 50 years underwent primary AVR in California and New York State from January 1, 1997, to December 31, 2014. Patients with 1 or more of the following criteria were excluded: concomitant mitral valve surgery (n = 2,874 [17.5%]), infective endocarditis (n = 2,001 [12.2%]), concomitant coronary artery bypass grafting (n = 1,604 [9.8%]), out-of-state residency (n = 1,085 [6.6%]), intravenous drug abuse (n = 766 [4.7%]), Marfan syndrome (n = 499 [3.0%]), concomitant tricuspid surgery (n = 336 [2.0%]), and carcinoid disease (n = 20 [0.01%]). After applying exclusion criteria, 8,813 patients remained, of whom 446 underwent a Ross procedure, 2,795 underwent a biological AVR, and 5,582 underwent mechanical AVR. Three-way 1:1:1 propensity score matching created 434 patients for each cohort (Supplemental Figure 6). In the overall cohort before propensity matching, those who underwent the Ross procedure were younger and generally with fewer comorbidities (Supplemental Table 3). In the propensity-matched cohort, there were no significant differences in patient demographic characteristics or comorbidities (**Table 1**).

SURVIVAL. In the propensity-matched cohort, 30-day mortality after the Ross procedure, biological AVR, and mechanical AVR was 0.23%, 0.69%, and 0.69%, respectively ($P = 0.71$). At 15 years, actuarial survival was 93.2% (95% CI: 89.0%-95.9%), 87.9% (95% CI: 83.2%-90.6%), and 88.4% (95% CI: 84.4%-91.5%) after the Ross procedure, biological AVR, and

FIGURE 2 Long-Term Cumulative Incidence of Stroke



Number at Risk				
Bioprosthetic	434	381	283	111
Mechanical	434	364	276	126
Ross	434	375	295	125

At 15 years, the cumulative incidence of stroke after mechanical aortic valve replacement **(red)** is 4.8%, which is significantly higher than that observed after biological aortic valve replacement **(blue)** (3.3%) or the Ross procedure **(gray)** (2.1%).

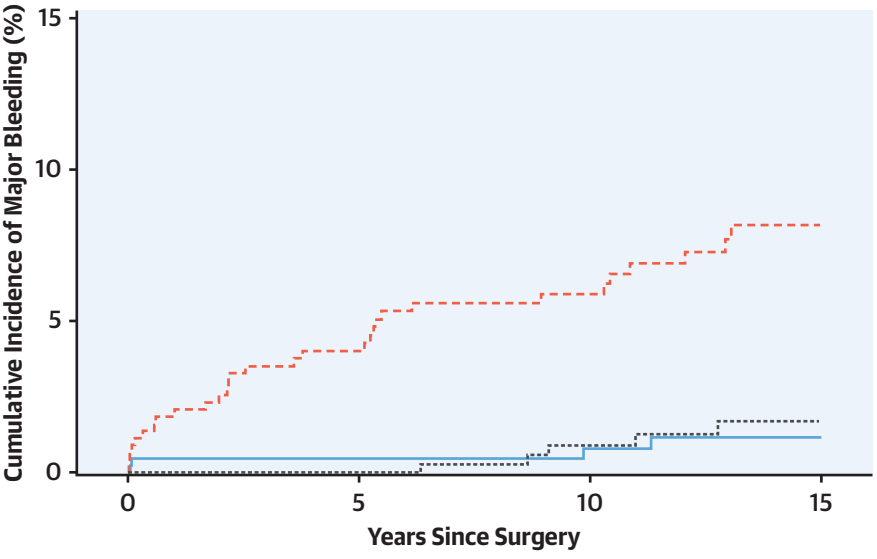
mechanical AVR, respectively (log-rank test, $P = 0.005$) (Figure 1). Survival after the Ross procedure was similar to the age-, sex-, and race-matched U.S. general population (HR: 0.97; 95% CI: 0.94-1.01). In contrast, the Ross procedure was associated with significantly lower risk of mortality compared to biological AVR (HR: 0.42; 95% CI: 0.23-0.75; $P = 0.003$) and to mechanical AVR (HR: 0.45; 95% CI: 0.26-0.79; $P = 0.006$).

STROKE. At 15 years, the cumulative incidence of stroke was 2.1% (95% CI: 0.9%-4.2%), 3.3% (95% CI: 1.6%-6.0%), and 4.8% (95% CI: 2.9%-7.3%) after the Ross procedure, biological AVR, and mechanical AVR, respectively (Figure 2). Overall, 30-day mortality after a stroke was 5.6%. Although there was no difference in the long-term risk of stroke after a Ross procedure compared with biological AVR (HR: 0.61; 95% CI: 0.24-1.57; $P = 0.30$), it was significantly lower than after mechanical AVR (HR: 0.37; 95% CI; 0.16-0.89; $P = 0.03$).

MAJOR BLEEDING. At 15 years, the cumulative incidence of major bleeding was 1.9% (95% CI: 0.8%-3.9%), 3.3% (95% CI: 1.8%-5.5%), and 5.2% (95% CI: 3.2%-7.8%) after the Ross procedure, biological AVR, and mechanical AVR, respectively (Figure 3). Overall, 30-day mortality after a major bleeding event was 2.6%. Although the risk of major bleeding was not different after a Ross procedure or biological AVR (HR: 0.50; 95% CI: 0.19-1.32; $P = 0.16$), it was significantly lower after the Ross procedure than mechanical AVR (HR: 0.32; 95% CI: 0.13-0.81; $P = 0.016$).

REOPERATION. At 15 years, the cumulative incidence of any aortic and/or pulmonary valve reintervention was 17.2% (95% CI: 13.2%-21.6%), 29.8% (95% CI: 24.5%-35.4%), and 7.4% (95% CI: 4.9%-10.5%) after the Ross procedure, biological AVR, and mechanical AVR, respectively (Figure 4). Overall, 30-day mortality after reoperation was 1.1% (Table 2). The Ross procedure was associated with a lower overall risk of reoperation than biological AVR (HR: 0.63; 95% CI: 0.45-0.88; $P = 0.008$). The proportional hazards assumption was violated in the comparison between the Ross procedure and biological AVR; the HRs were 1.57 (95% CI: 0.99-2.50) at 5 years and 0.19 (95% CI: 0.10-0.36) at 15 years. In contrast, the risk of reoperation was significantly higher than after mechanical AVR (HR: 2.4; 95% CI: 1.5-3.8; $P = 0.0002$). The cumulative incidence of pulmonary valve replacement after the Ross procedure is shown in Supplemental Figure 7.

FIGURE 3 Long-Term Cumulative Incidence of Major Bleeding



Number at Risk				
Bioprosthetic	434	384	288	112
Mechanical	434	355	276	122
Ross	434	376	295	126

At 15 years, the cumulative incidence of major bleeding was 5.2% after mechanical aortic valve replacement **(red)**, which is significantly higher than that observed after biological aortic valve replacement **(blue)** (3.3%) or the Ross procedure **(gray)** (1.9%).

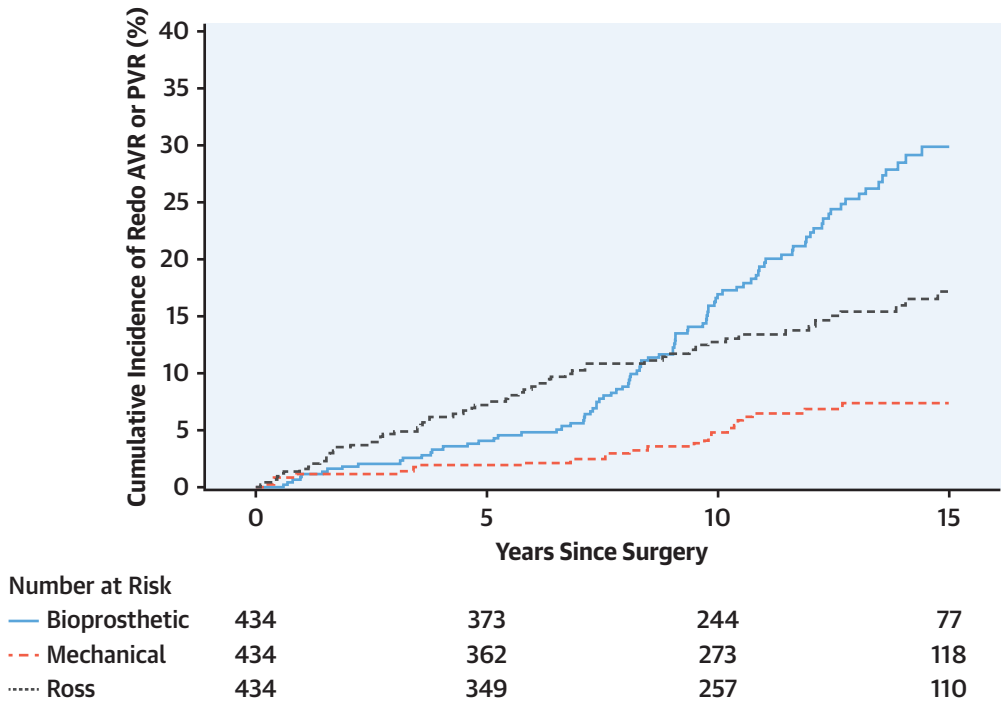
ENDOCARDITIS. At 15 years, the cumulative incidence of endocarditis was 2.3% (95% CI: 1.1%-4.3%), 8.5% (95% CI: 5.8%-12.0%), and 3.7% (95% CI: 2.0%-6.1%) after the Ross procedure, biological AVR, and mechanical AVR, respectively (Figure 5). Overall, 30-day mortality after endocarditis was 13.5%. The Ross procedure was associated with a lower risk of endocarditis than biological AVR (HR: 0.37; 95% CI: 0.17-0.80; $P = 0.012$) but was similar to mechanical AVR (HR: 0.61; 95% CI: 0.25-1.50; $P = 0.61$).

DISCUSSION

The main findings from this study are that: 1) in young adults, the Ross procedure is associated with better long-term survival than prosthetic AVR; 2) the risk of reintervention and endocarditis is significantly lower after a Ross procedure than with bioprosthetic valves; 3) in contrast, although the rate of reintervention was lowest with mechanical AVR, this was associated with a significantly higher risk of major bleeding or stroke over time; and 4) 30-day mortality after different valve-related complications varied widely, being lowest after a reintervention and highest after endocarditis, stroke, or major bleeding (Central Illustration).

In the last decade, several studies have consistently reported survival equivalent to the age- and sex-matched general population after the Ross procedure.[1,2,6] Furthermore, comparisons vs homografts or mechanical AVR within institutions showed better outcomes after the Ross procedure.[7,8] Nevertheless, most of these studies were single-center (and often single-surgeon) experiences. The current study sought to overcome these limitations by examining statewide data, thus pooling results from different surgeons over a period of time. In addition, we purposefully excluded any patient- or procedure-related factors that might affect long-term clinically relevant outcomes, such as survival, reoperation, endocarditis, or thromboembolic events. Finally, by focusing on adults <50 years old, the study further eliminates any possible unmeasured confounders associated with the choice of prosthesis in patients aged >50 years. Thus, this study best represents a real-life, multicenter, head-to-head comparison of the impact of valve choice on long-term clinical outcomes in young adults. However, this was not a prospective

FIGURE 4 Long-Term Cumulative Incidence of Any Aortic and/or Pulmonary Reoperation



At 15 years, the cumulative incidence of any reintervention was significantly lower after mechanical aortic valve replacement **(red)** (7.2%). In contrast, cumulative incidence of aortic and/or pulmonary valve reintervention was 17.2% after the Ross procedure **(gray)** and 29.8% after a biological aortic valve replacement **(blue)**.

randomized trial and thus cannot control for all potential confounders or biases.

The main finding from the current study is that the choice of valve substitute in young patients undergoing AVR has a direct impact on long-term survival. Although that difference may be partly attributable to patient selection and quality of patient follow-up, it is more likely a result of the unique hemodynamic and biological properties of the living pulmonary autograft. Indeed, the aortic valve is far more than a passive structure that opens and shuts in response to changes in transvalvular pressure. Instead, together with the other component parts of the aortic root, it actively contributes to perfect laminar blood flow, optimal left ventricular workload, and maximal coronary flow reserve by adapting to changing hemodynamic conditions. The pulmonary autograft is the only living aortic valve substitute, and as such it adapts to its new environment by adopting an aortic phenotype, which translates into near-normal root dynamics and valve performance, both at rest and with exercise.[9,10] In contrast, patient-prosthesis mismatch is a frequent problem after prosthetic AVR that is observed in up to 40% of patients at the time of hospital discharge.[11,12] Previous studies have shown that the presence of patient-prosthesis mismatch, especially in young adults, is associated with worse long-term outcomes, both in terms of structural valve degeneration and survival.[13,14]

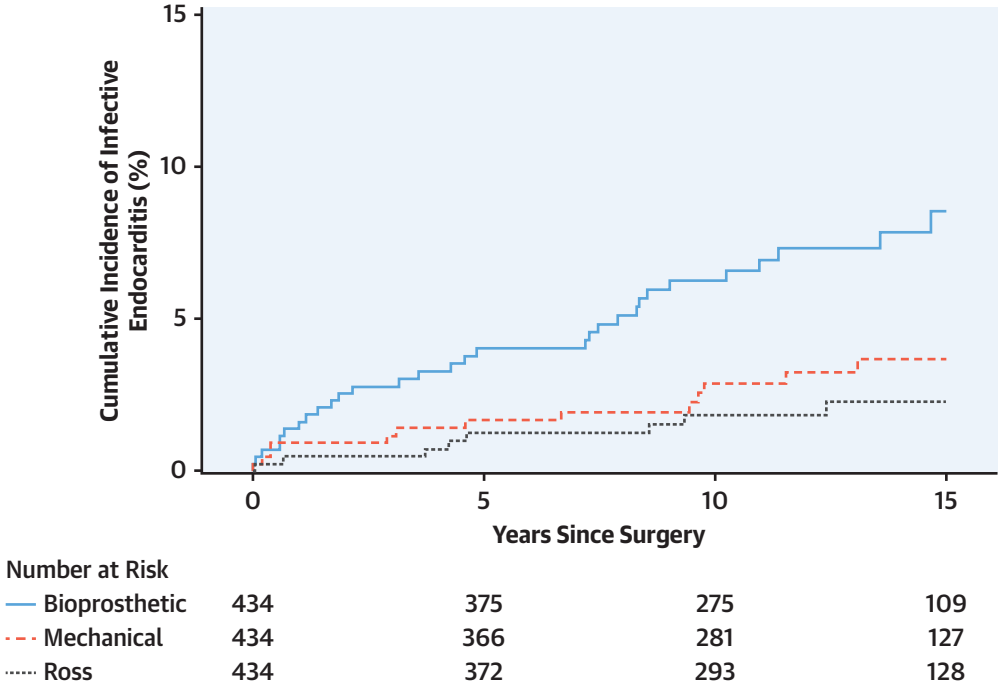
The choice of valve prosthesis often revolves around the durability issue, which explains the guideline recommendations favoring mechanical AVR in patients aged <50 years. Nevertheless, although reintervention represents a major inconvenience to the patient and an associated risk inherent to the

TABLE 2 30-Day Mortality After Different Valve-Related Complications

Valve-Related Complication	30-Day Mortality
Stroke	5.6
Endocarditis	13.5
Major bleeding	2.6
Reoperation	1.1

Values are %.

FIGURE 5 Long-Term Cumulative Incidence of Endocarditis



At 15 years, the cumulative incidence of endocarditis was significantly higher after biological aortic valve replacement **(blue)** (8.5%) compared with mechanical aortic valve replacement **(red)** (3.7%) or the Ross procedure **(gray)** (2.3%).

reintervention, the incidence and impact of other valve-related complications should not be overlooked. In the current study, which focused on otherwise healthy young patients, the cumulative incidence of stroke or major bleeding in patients undergoing a mechanical AVR was ~1% per year. Moreover, associated 30-day mortality after stroke or major bleeding was 5.6% and 2.6%, respectively. In contrast, 30-day mortality after a repeat surgery in this study was 1.1%. These are sobering results and should be clearly articulated to patients as part of the shared decision-making algorithm. These data are consistent with previously reported outcomes. In a comparable patient population of young patients undergoing mechanical AVR (mean age 34 years) from the Toronto group, the cumulative risk of stroke (excluding transient ischemic attacks) or major bleeding was >1% per year.[15] Data examining the systematic use of home anticoagulation monitoring represent possible avenues of improvement. A propensity-matched analysis comparing home anticoagulation monitoring after mechanical AVR vs the Ross procedure reported similar outcomes between the 2 groups, although the mean follow-up period was limited (~6 years).[16] Similarly, lower international normalized ratio targets with some valve models could prove beneficial. Nevertheless, the risk of thromboembolism or bleeding remains inherently higher when anticoagulation is required, whether with warfarin or factor Xa inhibitors. Furthermore, the psychological burden of anticoagulation in some patients, although hard to quantify, should not be ignored.[17]

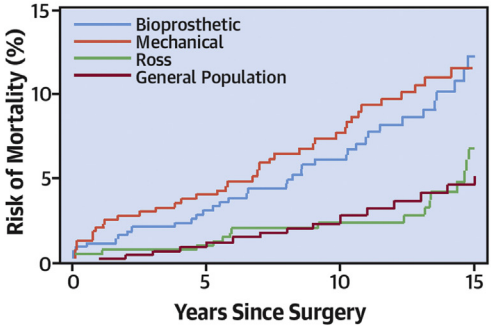
Freedom from reintervention after the Ross procedure represents one of the Achilles heels of the operation, especially because of the potential need for reintervention on 2 valves. The risk of reintervention is intricately related to surgical technique. Today, in addition to concentration of care in centers of expertise, the key technical principles associated with improved long-term durability are well understood, including pulmonary autograft muscle trimming, intra-annular implantation in the left ventricular outflow tract, elimination of supracommissural pulmonary artery tissue, use of decellularized homografts, and postoperative blood pressure management.[18] As a result, many surgeons performing the Ross procedure have modified their surgical technique over the years, which has resulted in improved durability.[19] The current study includes

CENTRAL ILLUSTRATION **Long-Term Outcomes After the Ross Procedure vs Prosthetic Aortic Valve Replacement in Adults**

Ross vs Biological vs Mechanical AVR

- New York and California Statewide Data (1997-2014)
- Adults needing elective isolated AVR (18-50 years old)
- Exclusions: Concomitant procedures, reoperations, IV drug use, dialysis, endocarditis, history of cancer, connective tissue disorders
- 1:1:1 propensity matching (Ross: Biological: Mechanical)
- N = 434 patients per cohort
- Median follow-up: 12.5 years

1 Ross Procedure = Better Survival (*equivalent to the general population*)



2 Ross Procedure = Lower Valve-Related Complications

- ↓ Endocarditis
- ↓ Reoperation

} vs Biological AVR

- ↓ Stroke
- ↓ Major Bleeeding

} vs Mechanical AVR

3 30-Day Mortality After Valve-Related Complications

Valve-Related Complications	30-Day Mortality
Stroke	5.6%
Endocarditis	13.5%
Major Bleeding	2.6%
Reoperation	1.1%

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The Ross procedure provides better survival compared with mechanical or biological aortic valve replacement (AVR) in young adults undergoing isolated AVR. Survival after the Ross procedure was equivalent to that in the matched U.S. general population. In addition, the Ross procedure was associated with overall better freedom from valve-related complications than prosthetic AVR. Interestingly, 30-day mortality after different valve-related complications varies widely. It was lowest after reoperation compared with endocarditis, stroke, or major bleeding. These findings further confirm the notion that a living valve substitute translates into better clinically relevant outcomes compared with prosthetic valves. The role of the Ross procedure in adults should be reconsidered in today's armamentarium.

patients dating back to 1997, thus incorporating the early days of the Ross experience in the United States. In this cohort, the cumulative risk of aortic and/or pulmonary reintervention after the Ross procedure of 1.2% per year lies between that of biological and mechanical AVR. These results are consistent with previously published long-term Ross series[1,20] and are expected to improve with more recent technical and technological modifications (eg, decellularized pulmonary homografts).

CLINICAL IMPLICATIONS. The most recent American College of Cardiology/American Heart Association guidelines for the management of valvular heart disease suggest a shared decision-making process, taking into account patient values and preferences.[3] In patients <50 years of age, a mechanical valve is proposed as the prosthesis of choice, whereas a biological valve represents the alternative if anticoagulation is contraindicated or undesirable. The Ross procedure is a Class IIb indication for young adults requiring aortic valve surgery. This represents a misalignment with best available evidence. Although guidelines aim to propose a roadmap for the majority of patients in the majority of centers, it is

nevertheless important to propose outcome-based recommendations, if appropriate expertise is available. As for mitral valve repair, it may be that recommendations should vary according to the availability of expertise with the Ross procedure. In the meantime, it is important for surgeons proficient in the Ross procedure to train the new generation of aortic surgeons to establish regional valve centers of excellence. The Ross procedure is undoubtedly a more complex and intricate operation than conventional AVR, with a definite learning curve.[21] The true challenge ahead is to standardize the operative steps and make it reproducible for aortic reconstructive surgeons. Indeed, as previously shown, operative risk compares favorably to prosthetic AVR if performed by surgeons with an interest and commitment to aortic root reconstructive surgery.[2,22] Importantly, public reporting of surgical outcomes along with patient-reported outcomes should be encouraged to ensure that patients can effectively make these critical life-altering choices.

STUDY LIMITATIONS. First, the use of administrative databases can introduce inaccuracies in coding, data retrieval, or reporting. We performed various tests to validate the quality of the data at a single high-volume institution, with good sensitivity and positive predictive value of the data. Second, as with all nonrandomized studies, there is always a possibility for unmeasured confounders. We sought to mitigate these biases by limiting the patient age to <50 years, excluding important comorbid conditions or concomitant procedures, and using propensity-matched analyses. Finally, use of administrative data precludes granularity in data collection, including specific causes of death and reintervention, which would be useful in understanding some of the observed differences. Similarly, surgeon-specific experience and its relationship with surgical outcomes could not be studied. Nevertheless, to mitigate this variable, the annual volume of AVR per hospital was used a surrogate for overall aortic valve surgical experience.

CONCLUSIONS

In this statewide propensity-matched comparison of young adults undergoing isolated AVR, the Ross procedure was associated with better long-term outcomes compared with prosthetic AVR. In particular, late survival after the Ross procedure was similar to that of the matched general population and better than that of biological or mechanical AVR. Although mechanical prostheses provide excellent durability, this approach is associated with a constant risk of major bleeding or stroke. Importantly, early mortality associated with different valve-related complications varies widely and is lowest if reintervention is needed. This study further confirms the notion that a living valve substitute in the aortic position translates into improvements in clinically relevant outcomes in young adults. The Ross procedure should be considered the option of choice for young adults requiring isolated replacement of the aortic valve, provided it is performed in centers with Ross procedure expertise to ensure safety and durability.

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PERSPECTIVES

COMPETENCY IN PATIENT CARE AND PROCEDURAL SKILLS: In a propensity-matched analysis involving young adults, the Ross procedure was associated with better long-term event-free survival than AVR with mechanical or biological prostheses.

TRANSLATIONAL OUTLOOK: Because the Ross procedure is more complex, further efforts are needed to standardize the operation, train the next generation of aortic surgeons to perform it, and establish objective measures to identify centers of expertise to improve access for young adults with aortic valve disease.

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APPENDIX For supplemental figures, tables, and methods, please see the online version of this paper.