Long-term outcome of bicuspid aortic valve repair using figure-of-8 hitch-up stitches

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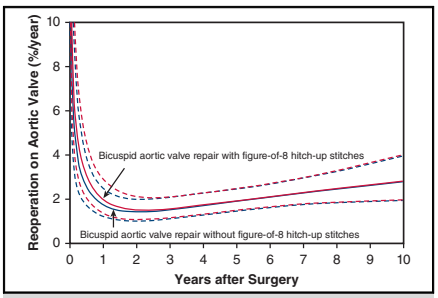
ABSTRACT

Objective: To maximize successful repair of bicuspid aortic valves by adding figure-of-8 hitch-up stitches at commissures.

Methods: From 2000 to 2022, bicuspid aortic valve repair was performed on 1112 patients at Cleveland Clinic, with 367 patients receiving figure-of-8 hitch-up stitches along with classical techniques, including Cabrol suture, cusp plication, raphe resection, and valve-sparing root replacement. Operative outcomes, repair durability, and survival were assessed in the figure-of-8 hitch-up stitches cohort, and outcomes were compared among 195 balancing-score-matched patient pairs who underwent bicuspid aortic valve repair with and without figure-of-8 hitch-up stitches.

Results: Patients who underwent bicuspid aortic valve repair with figure-of-8 stitches had an operative mortality of 0.3% (1 of 367) and in-hospital reoperation for aortic valve dysfunction of 1.1% (4 of 367). At 10 years, prevalence of severe aortic regurgitation was 8.6%, mean gradient 24 mm Hg, freedom from aortic valve reoperation 75%, and survival 98%. In matched cohorts, operative mortality was similar (0.51% vs 0%; $P > .9$) as were morbidities, including in-hospital reoperation due to aortic valve dysfunction (1.0% vs 1.5%; $P > .9$). Comparable long-term outcomes were observed at 10 years (prevalence of severe aortic regurgitation of 8.7% vs 5.0% [$P = .11$], mean gradient 18 vs 17 mm Hg [$P = .40$]; freedom from aortic valve reoperation 80% vs 81% [$P = .73$]; and survival 99.5% vs 94.6% [$P = .18$]).

Conclusions: Figure-of-8 hitch-up stitch is a safe bicuspid aortic valve repair technique. It increases the likelihood of a successful repair without increasing risk of cusp tear and achieves satisfactory long-term survival and durability when added to classical repair techniques. (JTCVS Techniques 2024;24:27-40)



Aortic valve reoperation after repair with and without figure-of-8 hitch-up stitches.

CENTRAL MESSAGE

Figure-of-8 hitch-up stitch is a safe technique to facilitate repair of bicuspid aortic valves when added to classical techniques and achieves good long-term durability and survival.

PERSPECTIVE

Figure-of-8 hitch-up stitch effectively corrects cusp prolapse and increases coaptation height in bicuspid aortic valve repair without increasing the risk of cusp tear, significant aortic valve dysfunction, or aortic valve reoperation. Our data suggest that figure-of-8 hitch-up stitches could be safely added to increase the success of repair for bicuspid aortic valve repair.

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Abbreviations and Acronyms
AV = aortic valve
BAV = bicuspid aortic valve
LV = left ventricular

Video clip is available online.

Bicuspid aortic valve (BAV) is a common congenital abnormality. Due to its bicuspid configuration, BAVs tend to progress to aortic valve (AV) dysfunction at an earlier age in patients than the general population,[1] presenting as moderate or severe aortic stenosis, typically in the fifth or sixth decade, with aortic regurgitation about a decade earlier.[2] For these young patients with bicuspid aortic regurgitation, AV repair is crucial to avoid lifetime anticoagulation of a mechanical valve prosthesis with its associated risk of thromboembolic or hemorrhagic sequelae.

Although tricuspid AV repair achieves perfect long-term durability when it is combined with root reimplantation,[3] the evaluation of long-term outcome of BAV repair has lagged.[4] However, over the past decade, we have progressed in understanding BAV root anatomy and surgical techniques.[5,6] Cleveland Clinic pioneered BAV repair in the 1980s.[7] In this study, we present an effective repair technique, figure-of-8 hitch-up stitches as we described earlier,[8] that might facilitate cusp repair in bicuspid aortic regurgitation.

Cleveland Clinic has utilized figure-of-8 hitch-up stitches for BAV repair since 2006, and previous studies have indicated that figure-of-8 hitch-up stitches might improve repair durability.[8] However, concerns still exist regarding their safety and durability, especially the risk of commissural tear and its effect on AV gradient.[6] In this study, we examine the early and long-term outcomes of patients who underwent BAV repair with figure-of-8 hitch-up stitches, and evaluate the causes of their repair failure compared with those patients who underwent BAV repair with only classical techniques (Figure 1).

PATIENTS AND METHODS

Patients and Data

From 2000 to 2022, 1160 patients underwent BAV repair at Cleveland Clinic. After excluding emergency surgery, type A dissection, endocarditis, and AV reoperation, we included 1112 patients in this study. Among these patients, 367 underwent BAV repair with figure-of-8 hitch-up stitches, and 745 without their use (Figures E1 and E2). The patients in the figure-of-8 hitch-up stitches cohort were slightly older (46 ± 13 vs 44 ± 13 years), had more female patients (15% vs 13%), and more had hypertension (62% vs 55%) (Table 1).

Baseline, procedural, and morbidity data were abstracted prospectively for quality reporting by independent registry nurses and entered into the Cardiovascular Information Registry. Transthoracic echocardiographic data were measured and entered into the echocardiography database by clinical echosonographers. Other Cleveland Clinic electronic medical record databases were also queried. All data used for this study were approved for use in research by the Cleveland Clinic Institutional Review Board, with patient consent waived (IRB #20-320; approved March 31, 2020).

Repair Techniques and Concomitant Procedures

At Cleveland Clinic, a typical repair for a BAV usually includes the release of a suspensory raphe to increase cusp mobility, Cabrol stitches to downsize aortic anulus and increase apposition of cusps, plication of prolapsed or incompletely fused conjoint cusps, and figure-of-8 hitch-up stitches. Figure-of-8 hitch-up stitches are chosen by surgeon preference or when a repair is not feasible with traditional techniques. However, we rarely use it in patients with small anulus to prevent aortic stenosis. For figure-of-8 hitch-up stitches, we place a polytetrafluoroethylene stitch over and over at the leading edge of the cusps near the commissures. We then pass the sutures 3 to 4 mm above the commissures about 3 to 4 mm apart and tie them outside over a pledget (Figure 2 and Video 1).

To address important root aneurysm, we routinely perform root remodeling or reimplantation in combination with BAV repair, depending on anular size and underlying etiology (whether it is connective tissue disorder or not). Among the 367 patients in the figure-of-8 hitch-up stitches group, 287 (78%) received ascending aortic repair; 9 (2.5%) hemiarch or total arch repair; and 9 coronary artery bypass (2.5%) (Table 1).

End Points

Operative morbidities and mortality. Operative mortality and major morbidities were defined as for the Society of Thoracic Surgeons National Database.[9]

Longitudinal echocardiographic outcomes. For longitudinal estimation of AV regurgitation, mean gradient, and left ventricular (LV) mass regression, all transthoracic echocardiograms performed at Cleveland Clinic or provided to the Clinic from elsewhere were reviewed and results stored in the echocardiography database. Aortic regurgitation was graded according to a semiquantitative scale as none or trace, mild, moderate, or severe. There were 885 echocardiogram records available for 79% (290 of 367) in the figure-of-8 stitches group, and 605 echocardiogram records available for 96% (184 of 195) matched patients in the no-figure-of-8 stitches group (Figures 3 and 4). All longitudinal measurements were censored at the time of reoperation.

Time-related AV reoperation and mortality. Patients were followed systematically at 1, 2, and 5 years, and at 5-year intervals thereafter for reoperations on the AV and vital status via mailed questionnaire or telephone contact with the patient or a family member. Median follow-up of figure-of-8 stitches cohort was 2 years, with 25% more than 5 years follow-up, and 10% more than 10 years. Median follow-up of the matched no-figure-of-8 stitches cohort was 3 years, with 25% more than 5 years, and 10% more than 10 years. Systematic follow-up for vital status was supplemented with Social Security Death Master File (to 2011) and Ohio State Death Registry data. Median follow-up for vital status in the figure-of-8 stitches cohort was 3 years, with 10% followed more than 12 years. In the matched no-figure-of-8 stitches cohort, median follow-up was 4 years and 10% underwent follow-up of more than 12 years.

Statistical Analysis

Statistical analyses were performed with SAS version 9.4 (SAS Institute Inc) and R version 3.6.0 (R Foundation for Statistical Computing). Continuous variables are summarized as mean ± standard deviation (SD) or as equivalent 15th, 50th (median), and 85th percentiles when distribution of values was skewed. Categorical data are summarized by frequencies and percentages. Differences between preoperative and operative characteristics of figure-of-8 stitches and no-figure-of-8 stitches groups are expressed as standardized

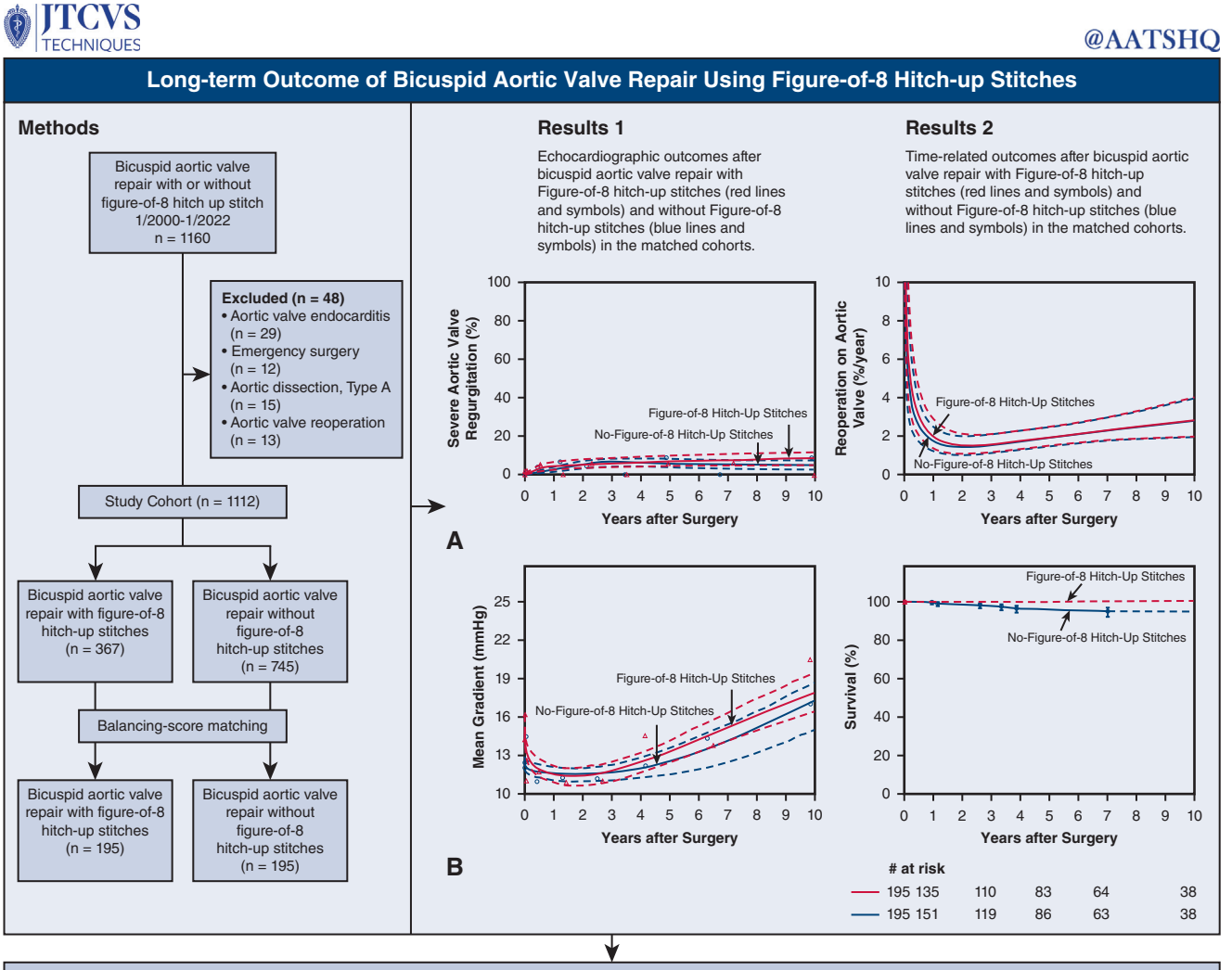


FIGURE 1. Graphical abstract. Figure-of-8 hitch-up stitch is a safe bicuspid aortic valve repair technique when completed in centers providing this level of expertise. *BAV*, Bicuspid aortic valve.

mean differences (%). Confidence intervals for longitudinal estimates used a bootstrap percentile method to obtain 68% confidence bands (equivalent to ±1 standard error [SE]) and the delta method for time-related events.

Balancing Score Rationale, Development, and Matching

Rationale. There were several differences in patient and procedure variables between the 2 cohorts (Table 1). We used balancing-score matching to reduce bias between the figure-of-8 stitches and no-figure-of-8 stitches groups for comparison of outcomes.

Missing values. We employed 5-fold multiple imputation[10] using multivariate imputation by chained equations to impute missing values. A parsimonious logistic regression model for distinguishing patients in the figure-of-8 stitches group from those in the no-figure-of-8 stitches group was then developed using the first imputation data set. For this, variable selection from those listed in Appendix E1 used bagging[11] based on automated analysis of 1000 bootstrap data sets (*C* statistic = 0.92) (Table E1).[10] Regression coefficients and their variance-covariance matrix were estimated for each of the 5 models, which were combined to yield final regression coefficient estimates, the variance-covariance matrix, and *P* values.[10]

Balancing score development. A balancing-score model was developed by adding nonsignificant variables to the parsimonious model representing patient demographics, symptoms, and cardiac and noncardiac comorbidity variables that might be related to unrecorded factors (saturated model with 50 variables) (*C* statistic = 0.93). The balancing score for each patient was obtained by averaging 5 balancing scores calculated from 5 saturated models based on the imputed data sets.[12]

Matching. Using only the balancing score, figure-of-8 stitches cases were matched 1:1 to no-figure-of-8 stitches cases using a greedy matching strategy[13] in the logit domain with a caliper width equal to 0.2 times the SD

TABLE 1. Baseline characteristics of patients with and without figure-of-8 hitch-up stitches: Original and propensity score-matched cohorts

	Original cohorts					Matched cohorts				
Characteristic	Figure-of-8 hitch-up stitches (n = 367)		STD	No-figure-of-8 hitch-up stitches (n = 745)		Figure-of-8 hitch-up stitches (n = 195)		STD	No-figure-of-8 hitch-up stitches (n = 195)	
Demographic										
Age (y)	367	46 ± 13	16 (−14 to 12)	745	44 ± 12	195	46 ± 13	15 (−21 to 22)	195	44 ± 13
Female	367	54 (15)	5.7 (−12 to 13)	745	95 (13)	195	31 (16)	−5.5 (−19 to 19)	195	35 (18)
Body mass index	367	28 ± 4.7	9.2 (−13 to 12)	745	28 ± 4.9	195	29 ± 4.7	13 (−19 to 17)	195	28 ± 5.2
Aortic valve regurgitation grade	366*		−36 (−13 to 13)	745		195		−14 (−22 to 21)	195	
None		90 (25)			116 (16)		43 (22)			33 (17)
Mild		60 (16)			86 (12)		21 (11)			30 (15)
Moderate		94 (26)			173 (23)		55 (28)			39 (20)
Severe		122 (33)			370 (50)		76 (39)			93 (48)
Aortic root size, diameter										
Aorta sinus (cm)	323*	4.1 ± 0.55	5.1 (−14 to 14)	524*	4.0 ± 0.57	173*	4.0 ± 0.52	9.0 (−23 to 24)	156*	3.9 ± 0.51
Mid ascending aorta (cm)	339*	4.5 ± 0.85	43 (−14 to 14)	650*	4.1 ± 0.79	181*	4.3 ± 0.80	10 (−20 to 23)	171*	4.1 ± 0.76
LV morphology and function										
End-diastolic volume index (mL/m^2)	345*	69 ± 27	−36 (−13 to 14)	665*	78 ± 29	185*	72 ± 28	−10 (−23 to 21)	177*	74 ± 28
End-systolic volume index (mL/m^2)	341*	26 ± 13	−33 (−13 to 13)	657*	31 ± 16	183*	27 ± 14	−9.1 (−22 to 21)	175*	28 ± 15
Mass index (g/m^2)	344*	118 ± 42	−32 (−14 to 13)	658*	130 ± 47	185*	124 ± 47	5.8 (−22 to 21)	176*	119 ± 45
Ejection fraction (%)	365*	59 ± 5.5	43 (−13 to 12)	741*	56 ± 7.5	194*	59 ± 5.9	8.3 (−19 to 19)	193*	58 ± 6.4
Relative wall thickness (cm)	344*	0.41 ± 0.096	11 (−13 to 13)	659*	0.39 ± 0.10	185*	0.41 ± 0.09	13 (−21 to 20)	176*	0.39 ± 0.12
Other cardiovascular comorbidities										
Atrial fibrillation/flutter	359*	7 (1.9)	−19 (−12 to 13)	709*	40 (5.6)	187*	5 (2.7)	−2.5 (−22 to 22)	194*	6 (3.1)
Congestive heart failure	367	20 (5.4)	−15 (−12 to 13)	744*	70 (9.4)	195	11 (5.6)	2.3 (−21 to 21)	195	10 (5.1)
Cardiac surgery	367	20 (5.4)	−7.4 (−13 to 12)	745	54 (7.2)	195	14 (7.2)	11 (−20 to 20)	195	9 (4.6)
Noncardiac comorbidities										
Pharmacologically treated diabetes	366*	14 (3.8)	12 (−15 to 12)	741*	14 (1.9)	194*	5 (2.6)	0 (−20 to 20)	194	5 (2.6)
COPD	367	23 (6.3)	1.5 (−13 to 13)	744*	44 (5.9)	195	12 (6.2)	−6.1 (−22 to 22)	195	15 (7.7)
Peripheral artery disease	367	7 (1.9)	−6.8 (−12 to 11)	744*	22 (3.0)	195	5 (2.6)	0 (−20 to 20)	195	5 (2.6)
Hypertension	367	229 (62)	16 (−13 to 13)	745	408 (55)	195	127 (65)	17 (−20 to 19)	195	111 (57)
Smoking	366*	123 (34)	−3.6 (−13 to 13)	739*	261 (35)	194*	69 (36)	11 (−17 to 17)	195	59 (30)
Dyslipidemia	356*	154 (43)	4.9 (−14 to 13)	698*	285 (41)	185*	78 (42)	13 (−21 to 22)	186*	67 (36)
Creatinine (mg/dL)	367	0.98 ± 0.18	−3.8 (−14 to 12)	745	0.98 ± 0.24	195	0.98 ± 0.17	5.9 (−21 to 21)	195	0.97 ± 0.17
Hematocrit (%)	367	43 ± 3.3	16 (−13 to 12)	745	43 ± 4.0	195	43 ± 3.4	−3.8 (−17 to 20)	195	43 ± 3.7
Concomitant procedures										
Ascending aortic repair	367	287 (78)	49 (−13 to 13)	741*	414 (56)	195	134 (69)	15 (−18 to 21)	193*	119 (62)
Arch repair	367	9 (2.5)	−35 (−13 to 13)	745	84 (11)	195	7 (3.6)	−5.2 (−21 to 21)	195	9 (4.6)
Coronary artery bypass grafting	367	9 (2.5)	−6.8 (−12 to 11)	745	27 (3.6)	195	5 (2.6)	3.4 (−17 to 17)	195	4 (2.1)
Procedure for atrial fibrillation	367	4 (1.1)	−25 (−13 to 11)	745	42 (5.6)	195	4 (2.1)	0 (−22 to 22)	195	4 (2.1)
Aortic repair techniques										
Root reimplantation	367	10 (2.7)	−61 (−13 to 12)	745	164 (22)	195	10 (5.1)	0 (−19 to 19)	195	10 (5.1)
Root remodeling	367	14 (3.8)	8.1 (−15 to 12)	745	18 (2.4)	195	5 (2.6)	3.4 (−17 to 17)	195	4 (2.1)
Cabrol suture	367	296 (81)	64 (−13 to 12)	745	386 (52)	195	139 (71)	11 (−20 to 18)	195	129 (66)
Cusp plication	367	137 (37)	−48 (−12 to 13)	745	451 (61)	195	84 (43)	−14 (−21 to 19)	195	98 (50)

Values are presented as n, n (%), or mean ± SD. *STD*, Standardized difference; *LV*, left ventricular; *COPD*, chronic obstructive pulmonary disease. *Patients with data available.

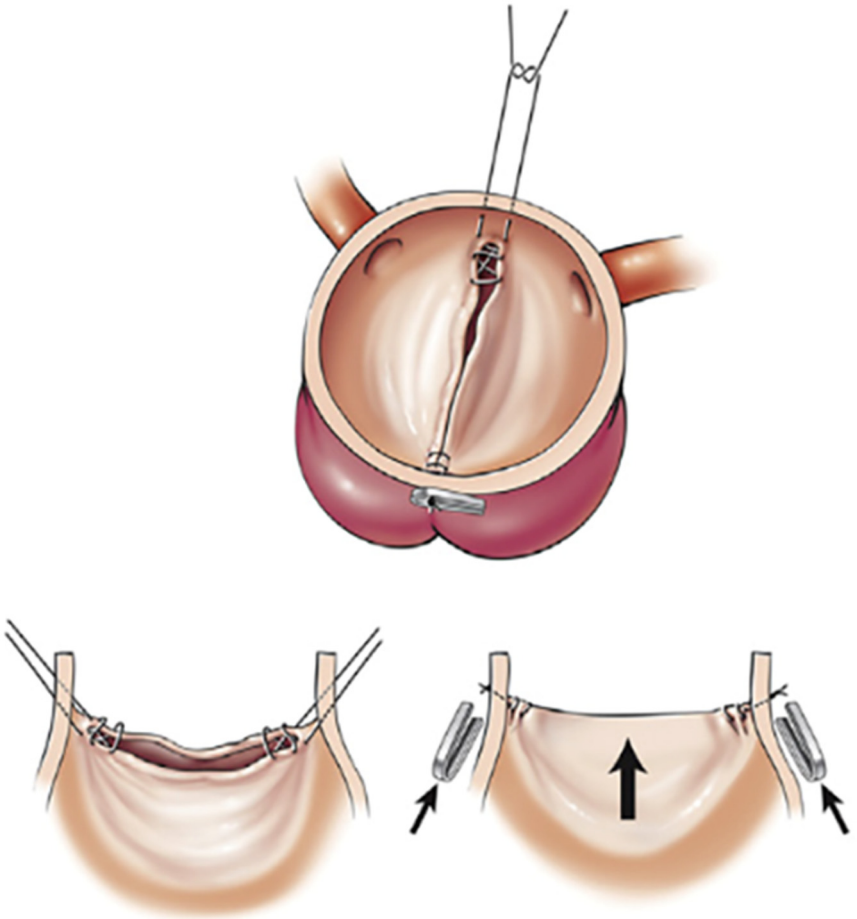
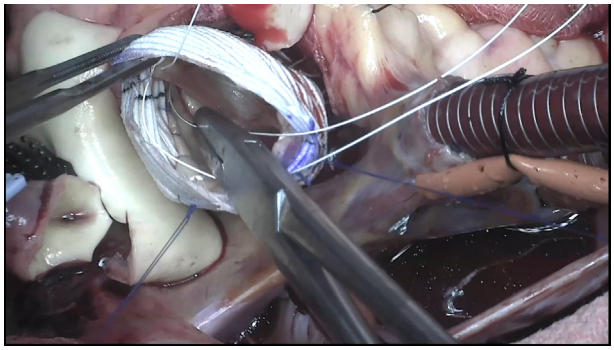


FIGURE 2. Aortic valve repair with figure-of-8 (Svensson) suspension sutures. The technique involves placing figure-of-8 suspensory sutures at the leading edge of the cusps. We use 5–0 polytetrafluoroethylene suture placed 3 to 4 mm above the commissure, which is then clipped to prevent unraveling. The technique is also used for tricuspid valves in conjunction with sinutubular-segment tailoring, but only selectively in the case of minor (<2 mm) commissural fenestrations.[8]

of the logit of the balancing score,[14] yielding 195 well-matched patient pairs (Figure E3). An absolute value of standard mean difference $\leq$10% is usually interpreted as acceptable matching.[15] However, when matching reduces the effective sample size, as in this study, there may be larger variability in standard mean difference that may yield some estimated absolute standard mean difference values >10%. To assess whether or not the true underling standard mean difference is zero, we estimated a 95% plausible interval using the empirical distribution of standard mean difference from 1000 permutations under the null hypothesis that population standard mean difference is zero.[16] Any estimated standard mean difference not falling within the interval was considered imbalanced. Comparison of continuous outcomes used the Wilcoxon rank-sum test, and categorical outcomes the χ^2 test or Fisher exact test as appropriate.



VIDEO 1. Surgical technique of figure-of-8 commissure realignment suture in a patient undergoing valve-sparing aortic root replacement with aortic valve reimplantation. Video available at: https://www.jtcvs.org/article/S2666-2507(24)00039-7/fulltext.

Echocardiographic Longitudinal Data Analyses

To assess the temporal trend of individual grades of postoperative aortic regurgitation (ordinal longitudinal data), follow-up transthoracic echocardiograms were analyzed longitudinally for pattern of change across time using a nonlinear, multiphase mixed-effects cumulative logit regression model.[17] Prevalence of each aortic regurgitation grade over time was estimated by averaging patient-specific profiles. A multiphase, nonlinear, mixed-effects regression model was used to similarly estimate the temporal ensemble average of postoperative mean gradient and LV mass index (continuous longitudinal data).[18]

Time-related analyses. Survival and freedom from AV reoperation were estimated nonparametrically by the Kaplan-Meier method and

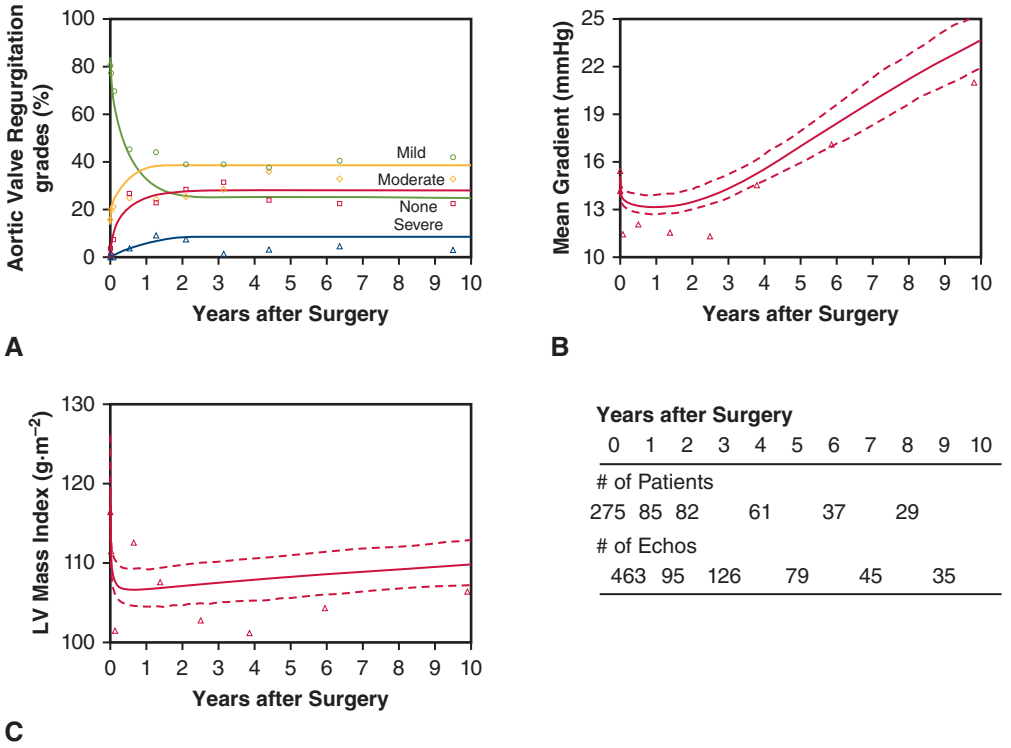


FIGURE 3. Longitudinal echocardiographic outcomes after bicuspid aortic valve repair with figure-of-8 hitch-up stitches. *Symbols* represent data grouped (without regard to repeated measurements) within time frames to provide a crude verification of model fit. A, Postoperative prevalence of aortic regurgitation grades. *Solid lines* represent longitudinal trend in aortic regurgitation grades. B, Temporal trend of postoperative aortic valve mean gradient. *Solid line* represents unadjusted estimates of temporal trend of postoperative aortic valve mean gradient enclosed within a 68% confidence band. C, Temporal trend of postoperative left ventricular (*LV*) mass index. Format is as in Figure 3, *B*.

parametrically by multiphase hazard methodology.[19] These are accompanied by 68% confidence limits and bands equivalent to ±1 SE.

RESULTS

Outcomes in Figure-of-8 Hitch-up Stitches Group

Operative mortality and morbidity. Among 367 patients, there was 1 operative death (0.27%). One patient (0.27%) experienced permanent stroke, and 4 (1.1%) underwent early in-hospital reoperations for valve dysfunction (Table 2). The median duration of stay in the intensive care unit was 28 hours (15th/85th percentile, 22/64 hours), and postoperative length of stay was 5 days (15th/85th percentile, 4/7 days).

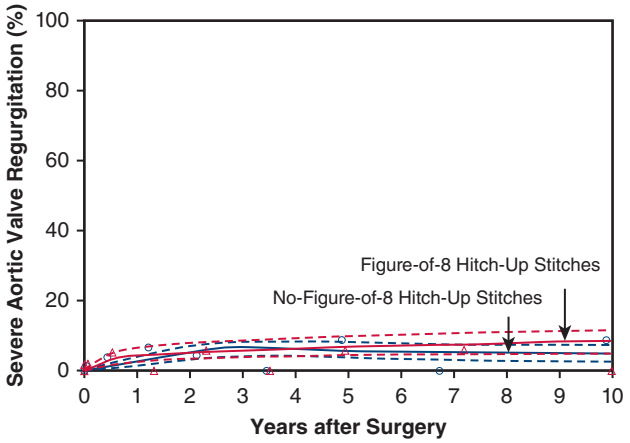
Longitudinal echocardiographic trends. At 10 years postoperatively, prevalence of moderate and severe aortic regurgitation was 28% and 8.6%, respectively (Figure 3, *A*); mean AV gradient was 24 mm Hg (Figure 3, *B*); and LV mass index was 110 g/m^2 (Figure 3, *C*).

Time-related reoperation and mortality. We observed 39 AV-dysfunction-related reoperations during follow-up (Table E2). Nine occurred within 1 year after the initial surgery. Of these, 6 were due to cusp tear (4 of which received in-hospital reoperations after the initial surgery), 2 due to cusp perforation, and 1 due to infective endocarditis. Thirty other patients underwent reoperation more than 1 year after the initial surgery. Of these, 16 were due to natural progression, 10 to cusp prolapse, 2 to infective endocarditis, and 1 to dilated aortic anulus.

Risk of reoperation was constant at around 2.8 reoperations per 100 patient-years after a decreased risk right after surgery (Figure 5, *A*). Freedom from AV reoperation at 1 year, 5 years, and 10 years after repair were 97%, 88%, and 75%, respectively (Figure 5, *B*). Survival estimates at 1 year, 5 years, and 10 years after repair were 99.6%, 99%, and 98%, respectively (Figure 5, *C*).

Outcomes of Matched Figure-of-8 Hitch-up Stitches Versus No-figure-of-8 Hitch-up Stitches Cohorts

Operative mortality and morbidity. Repair with figure-of-8 hitch-up stitches required significantly shorter aortic cross-clamp time compared with no use of figure-of-8 hitch-up stitches (median, 35 minutes; [15th/85th percentile, 26/60] vs 47 minutes [15th/85th percentile, 31/91 minutes]; $P < .0001$) and cardiopulmonary bypass time (median, 47 minutes [15th/85th percentile, 36/769 minutes] vs 61 minutes [15th/85th percentile, 39/111 minutes]; $P < .0001$). Operative outcomes were similar between the 2 matched groups (Table 2). Median postoperative length of stay was 5 days in both groups.



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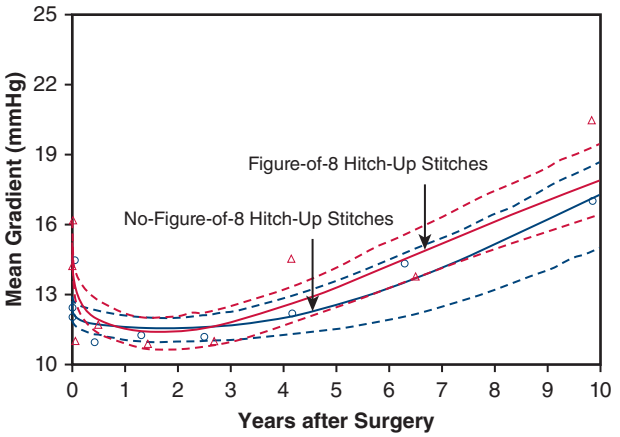

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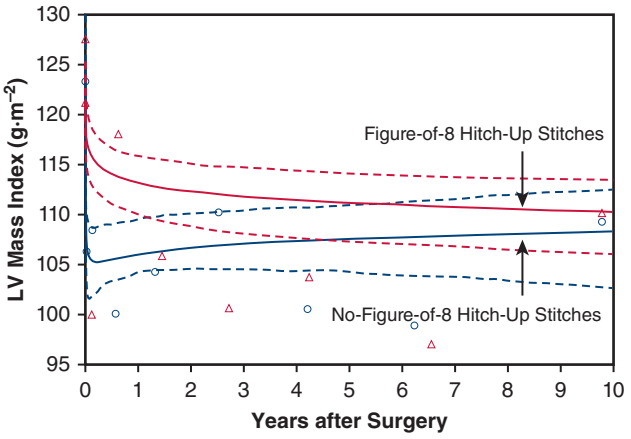


C

Years after Surgery	0	1	2	3	4	5	6	7	8	9	10
Figure-of-8											
# of Patients	149	37	39		30		21		18		
# of Echos	240	41		59		41		27		23	
No-Figure-of-8											
# of Patients	182	55	47		35		27		17		
# of Echos	325	62		69		58		38		26	

FIGURE 4. Comparison of longitudinal echocardiographic outcomes after bicuspid aortic valve repair with figure-of-8 hitch-up stitches (*red lines and symbols*) and without figure-of-8 hitch-up stitches (*blue lines and symbols*) in the matched cohorts. A, Postoperative prevalence of aortic regurgitation grades. Format as in Figure 3, *A*. B, Temporal trend of postoperative aortic valve mean gradient. Format as in Figure 3, *B*. C, Temporal trend of postoperative left ventricular mass index. Format is as in Figure 3, *B*. *LV*, Left ventricular.

Longitudinal echocardiographic trends. At 10 years postoperatively, the prevalence of severe aortic regurgitation was 8.7% in figure-of-8 stitches versus 5.0% in no-figure-of-8 stitches groups ($P = .11$) (Figure 4, *A*). The mean gradient at 10 years was 18 versus 17 mm Hg ($P = .80$) (Figure 4, *B*) and LV mass index was 110 g/m^2 versus 108 g/m^2 ($P = .90$) (Figure 4, *C*) in figure-of-8 stitches versus no-figure-of-8 stitches groups, respectively.

Time-related reoperation and mortality. There were 19 and 18 reoperations in the matched figure-of-8 stitches and no-figure-of-8 stitches groups, respectively. Among these, 5 in each group were due to cusp tear; 4 in each group were due to cusp prolapse; and 7 in figure-of-8 stitches group and 8 in no-figure-of-8 stitches group were due to natural progression. There was no significant difference in the risk of reoperation ($P = .73$) (Figure 6, *A*). Freedom from AV reoperation between the figure-of-8 stitches and no-figure-of-8 stitches groups was 96% versus 97% at 1 year, 90% versus 91% at 5 years, and 80% versus 81% at 19 years, respectively (Figure 6, *B*).

Ten deaths were observed during follow-up in the matched cohorts: 3 in figure-of-8 stitches group and 7 in no-figure-of-8 stitches group. Survival estimates in the figure-of-8 stitches and no-figure-of-8 stitches groups were 99.5% versus 99.4% at 1 year, 99.5% versus 96.1% at 5 years, and 99.5% versus 94.6% at 10 years after repair (P [log-rank] $= .18$) (Figure 6, *C*).

DISCUSSION

The current surgical options for young patients with BAV regurgitation include Ross, AV neocuspidization, valve repair, and other procedures. When anatomy permits, valve repair should be considered as a first option to offer in centers that provide this level of surgical expertise. Among different mechanisms contributing to aortic regurgitation in the BAV, prolapse of the fused cusp is almost always

TABLE 2. In-hospital outcomes of figure-of-8 hitch-up stitches group and propensity matched groups

Outcome	Total		Matched				
	Figure-of-8 hitch-up stitches (n = 367)		Figure-of-8 hitch-up stitches (n = 195)		No-figure-of-8 hitch-up stitches (n = 195)		
	n*	n (%) or 15th/median/85th percentile	n*	n (%) or 15th/median/85th percentile	n*	n (%) or 15th/median/85th percentile	*P* value
Operative death	367	1 (0.27)	195	1 (0.51)	195	0 (0)	>.9
Permanent stroke	367	1 (0.27)	195	1 (0.51)	195	1 (0.51)	>.9
Reoperation for valve dysfunction	367	4 (1.1)	195	2 (1)	195	3 (1.5)	>.9
Reoperation for bleeding or tamponade	367	3 (0.82)	195	1 (0.51)	195	4 (2.1)	.38
Any blood product transfusion	367	84 (23)	195	34 (17)	195	48 (25)	.082
New requirement for dialysis	339	1 (0.29)	176	1 (0.57)	175	0 (0)	>.9
Prolonged ventilation	364	11 (3)	192	7 (3.6)	191	1 (0.52)	.07
New postoperative atrial fibrillation	352	65 (18)	182	34 (19)	188	25 (13)	.16
Aortic clamp time (min)	367	27/36/55	195	26/35/60	194*	31/47/91	<.0001

*Patients with data available.

present. It is critical to effectively correct cusp prolapse without sacrificing the AV opening area during BAV repair.[20] Current options to address cusp prolapse include free margin plication, triangular resection, and commissuroplasty. However, our data have shown that cusp resection leads to inferior durability.[21] Sometimes cusp plication is not adequate to address cusp prolapse because the extension of plication needs to be very limited

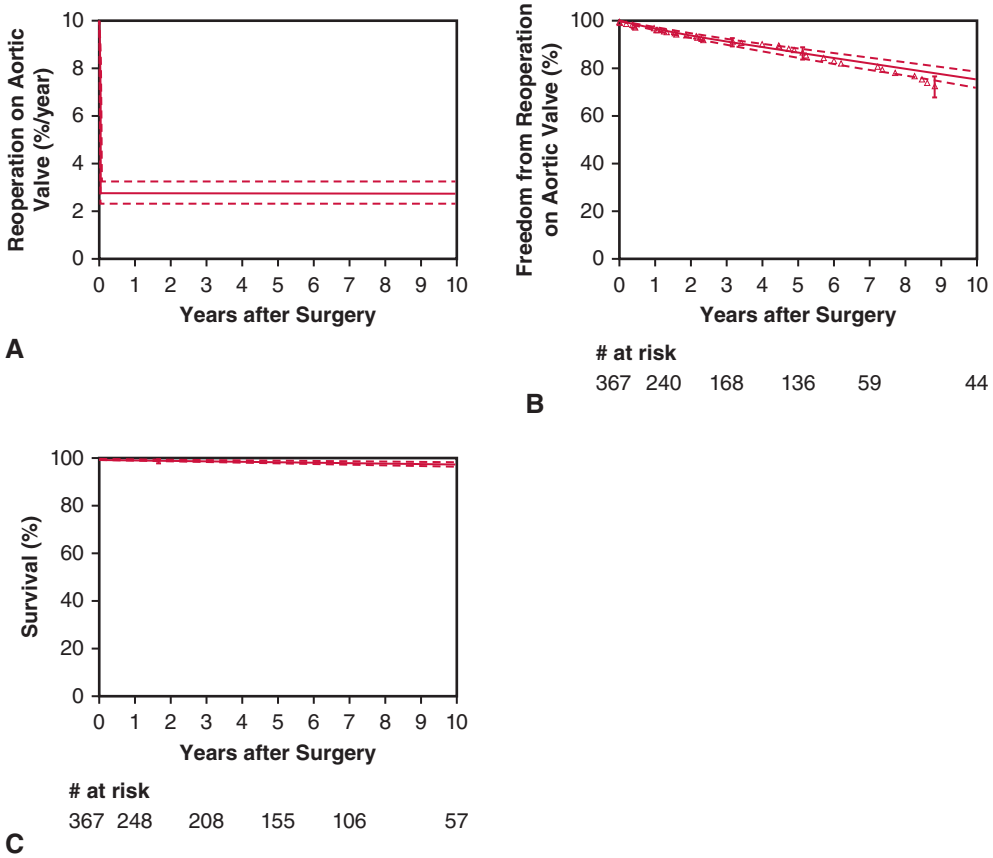
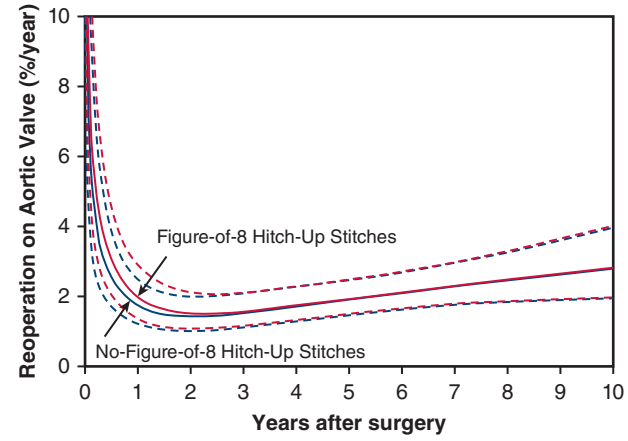


FIGURE 5. Time-related outcomes after bicuspid aortic valve repair with figure-of-8 hitch-up stitches. A, Instantaneous risk of aortic valve reoperation. *Solid line* is parametric estimate enclosed within dashed 68% confidence band. B, Freedom from aortic valve reoperation. *Solid line* is parametric estimate enclosed within dashed 68% CI. *Each symbol* represents a Kaplan-Meier estimate of the event, and vertical bars are 68% confidence limits equivalent to ±1 SE. Numbers below horizontal axis are patients remaining at risk. C, Survival. Format is as in Figure 5, *B*.



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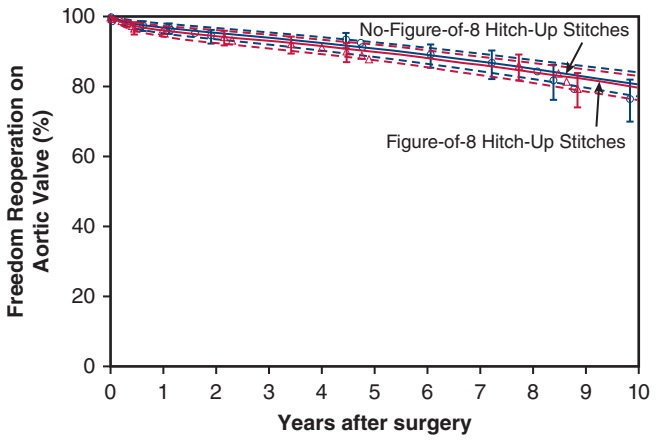
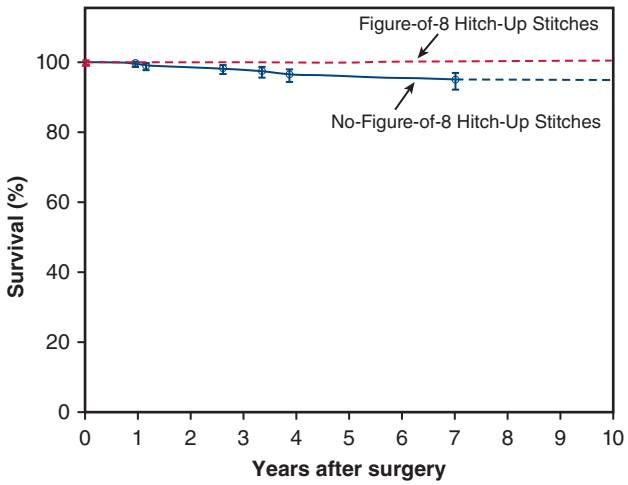


# at risk					
Figure-of-8 Hitch-Up Stitches					
195	128	93	73	46	31
No-Figure-of-8 Hitch-Up Stitches					
195	147	94	77	39	27

B



# at risk					
Figure-of-8 Hitch-Up Stitches					
195	135	110	83	64	38
No-Figure-of-8 Hitch-Up Stitches					
195	151	119	86	63	38

C

FIGURE 6. Comparison of time-related outcomes after bicuspid aortic valve repair with figure-of-8 hitch-up stitches (*red lines and symbols*) and without figure-of-8 hitch-up stitches (*blue lines and symbols*) in the matched cohorts. A, Instantaneous risk of aortic valve reoperation. Format as in Figure 5, *A*. B, Freedom from aortic valve reoperation. Format is as in Figure 5, *B*. C, Survival. Format is as in Figure 5, *B*.

to avoid possible stenosis. In addition, higher coaptation is required for a durable BAV repair in the majority of cases. Having been of the conviction that placing commissures at a higher level would increase the coaptation area of the cusps and correct and compensate for prolapse, we started to use figure-of-8 hitch-up stitches 17 years ago. This technique can also move a commissure in the opposite direction to a prolapsing cusp if needed.[5] It increases the tension of the prolapsing leading edge, which is particularly important in case of valve-preserving root reimplantation. This reduces intercommissural distance and frequently results in relevant cusp prolapse. Moreover, use of figure-of-8 hitch-up stitches closes off fenestrations at the commissures.

During the past 2 decades, we have successfully repaired >90% of BAVs in patients using comprehensive repair techniques, including figure-of-8 hitch-up stitches—some of

which otherwise would not be repairable. In this consecutive cohort of 367 patients who required figure-of-8 hitch-up stitches, patients had very low incidences of operative mortality (1 of 367) and major morbidity. Compared with a matched no-figure-of-8 hitch-up stitches group, the figure-of-8 hitch-up stitches group had significantly shorter aortic clamp and cardiopulmonary bypass times, which indicated that figure-of-8 hitch-up stitches would be able to facilitate BAV repair and make it more straightforward. Early outcomes, including early repair failure and early AV reoperation, were equivalent between the 2 matched groups.

Late follow-up showed a similar risk of AV dysfunction, AV reoperation, and death. Although there may be a concern about using figure-of-8 hitch-up stitches due to the risk of cusp tear and the effect on AV gradient, we did not observe a significant difference between the 2 matched groups. Our explanation is that the polytetrafluoroethylene suture we used for figure-of-8 hitch-up stitches may provide some elasticity in absorbing the pressure load of the returning diastolic pressure wave. The sutures are close to the site of the implantation of the apex of the commissures to the aortic wall and may compensate for the stress figure-of-8 hitch-up stitches puts on the pericommissural areas of the cusps. On the other hand, although our echocardiogram follow-up showed an ever-increasing AV gradient after 2 to 3 years following the index repair, there is no difference between the 2 groups either before or after matching, which indicates that this gradual increase of AV gradient is mostly due to natural progression of the bicuspid valve, and the use of figure-of-8 hitch-up stitches does not accelerate this progression.

Limitations

This is a single-institution series of prospectively collected data in our registry, not a randomized trial. Morphometric details of the AV have not been collected before repair. In addition, echocardiographic data were available only for patients routinely followed at our institution, generally at yearly intervals, which may have affected the results.

CONCLUSIONS

Figure-of-8 hitch-up stitch is a safe BAV repair technique. It corrects cusp prolapse and increases coaptation height. Meanwhile, it does not increase the risk of cusp tear or AV reoperation. Figure-of-8 hitch-up stitches achieve satisfactory long-term survival and durability, which indicates that it could be added to the BAV repair toolbox.

Conflict of Interest Statement

Dr Desai has consultant and research agreements with Bristol Myers Squibb, Tenaya, and Cytokinetic, and is a consultant for Medtronic. Dr Vargo is a speaker for Edwards Lifesciences and a consultant for Artivion and Cellphire. Dr Roselli is a consultant, investigator, and speaker for Artivion, Edwards Lifesciences, WL Gore, Medtronic, and Terumo Aortic; a speaker for Cook Medical, Corcym, and JenaValve; and has a license with Artivion. All other authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling 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: balancing score, reoperation, survival, valve-sparing root replacement

APPENDIX E1. VARIABLES CONSIDERED IN THE ANALYSIS. *VARIABLES INCLUDED IN THE PROPENSITY MODEL

Preprocedural Patient- and Valve-related Characteristics

Demographics. Age (years),* gender,* race* (White, Black, other), height (cm), weight (kg), body mass index (BMI, $kg \cdot m^{-2}$),* body surface area (BSA, m^2)

Ventricular function. Left ventricular ejection fraction*

Aortic valve hemodynamics. Aortic valve mean gradient,* aortic valve regurgitation,* aortic valve stenosis*

Other valve pathophysiology. Mitral valve regurgitation,* pulmonary valve regurgitation,* tricuspid valve regurgitation*

Valve etiology (other than connective tissue disorder). Degenerative mitral valve disease*

Aorta Dimension. Aortic root (sinus) diameter (cm),* mid ascending aorta diameter*

Left ventricular structure. Inner end-diastolic diameter (cm), inner diastolic volume (mL), inner diastolic volume index (mL/m^2),* inner end-systolic diameter (cm), left ventricular inner systolic volume (mL), left ventricular inner systolic volume index (mL/m^2)*

Left ventricular mass. Posterior wall thickness (cm), relative wall thickness (cm)*, Interventricular septal thickness (cm), left ventricular mass (g), left ventricular mass index*

Left atrial dimensions. Left atrial diameter (cm), left atrial volume (mL), left atrial volume index (mL/m^2)*

Cardiac comorbidity. Atrial fibrillation,* congestive heart failure,* cardiac surgery,* endocarditis*

Noncardiac comorbidity. Bilirubin, creatinine,* blood urea nitrogen,* hematocrit,* peripheral artery disease,* history of diabetes,* history of hypertension,* history of smoking,* chronic obstructive pulmonary disease,* history of dyslipidemia*

Concomitant procedure. Coronary artery bypass graft,* aortic arch procedure,* ascending aorta procedure,* atrial fibrillation procedure,* congenital atrial septal defect/patent foramen ovale suture closure*

Repair technique. Cabrol suture,* cusp plication,* cusp commissural resuspension suture,* cusp free edge reinforcement,* cusp debridement,* cusp resection suture,* division of fused cusp raphe,* valve-sparing root remodeling,* valve-sparing root reimplantation*

Experience. Date of surgery*

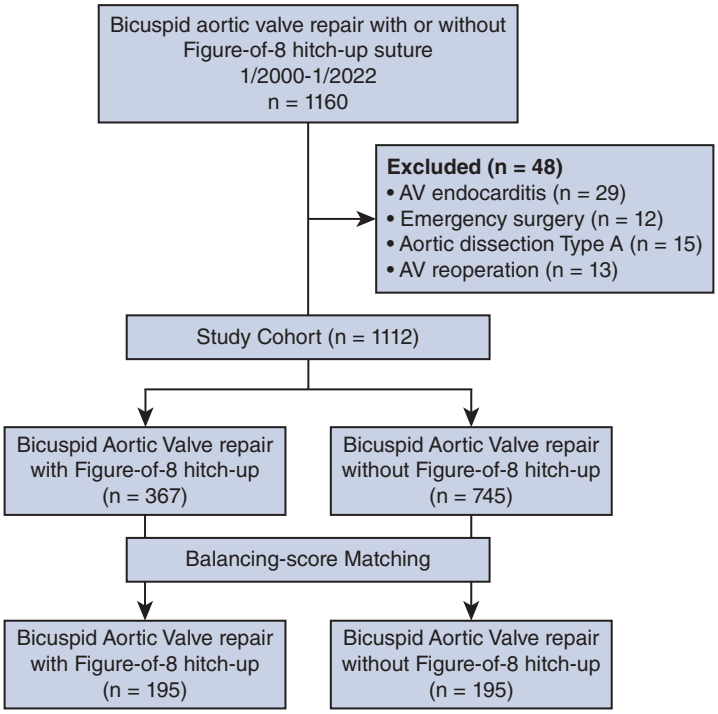
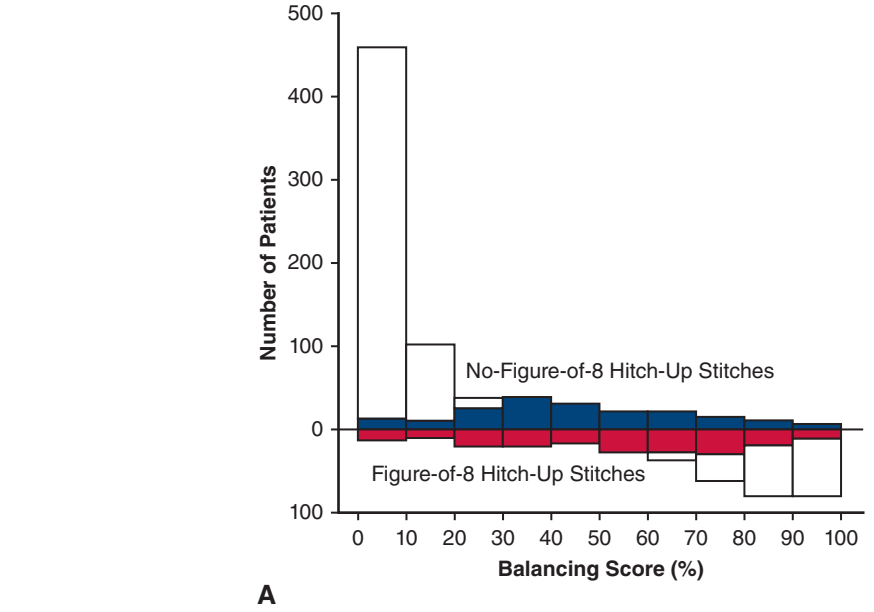


FIGURE E1. Consolidated Standards of Reporting Trials-style diagram of patients undergoing bicuspid aortic valve repair with and without figure-of-8 hitch-up stitches. *AV*, Aortic valve.

FIGURE E2. Temporal trend of number of patients undergoing bicuspid aortic valve repair with figure-of-8, hitch-up stitches (*red lines and symbols*) and without figure-of-8 hitch-up stitches (*blue lines and symbols*) over the study period. Symbols are yearly number of cases in each group.



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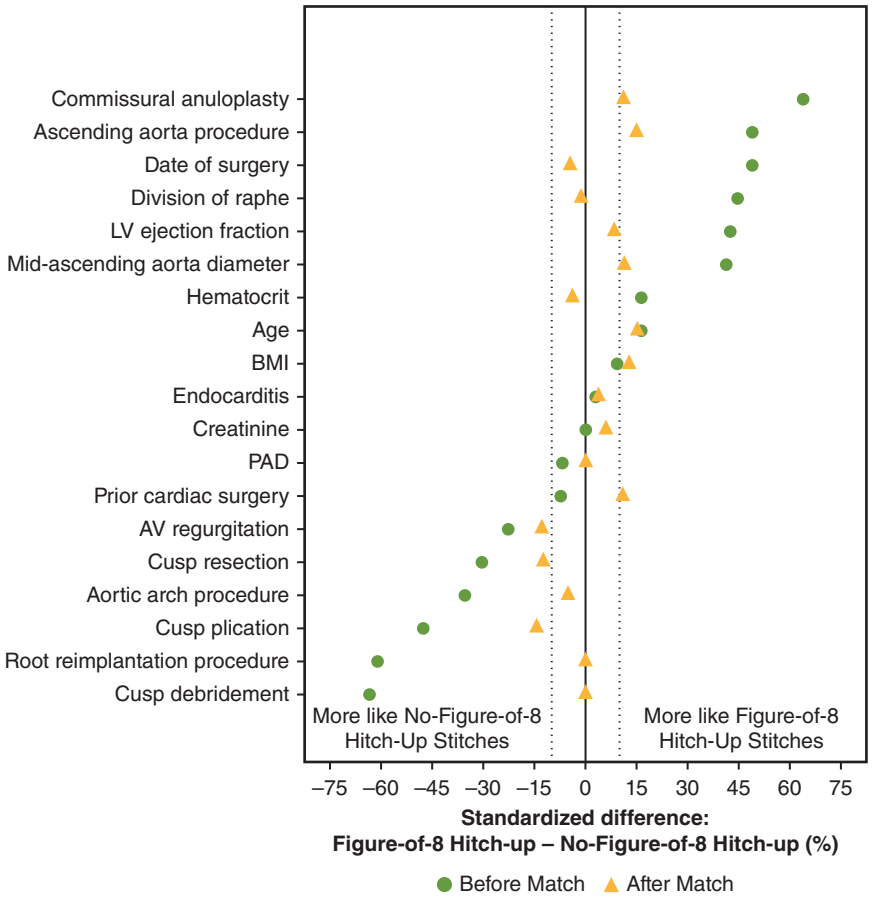

B

FIGURE E3. Quality of balancing score matching of patients undergoing biscuspid aortic valve repair with figure-of-8 hitch-up stitches. A, Mirrored histogram of distribution of balancing scores for both groups. *Shaded areas* represent matched patient pairs. B, Standardized differences of selected variables before and after matching. *Vertical dashed lines* at −10% and +10% indicate boundaries of desirable matching. *LV*, Left ventricular; *BMI*, body mass index; *PAD*, peripheral artery disease; *AV*, aortic valve.

TABLE E1. Factors associated with bicuspid aortic valve repair with and without figure-of-8 hitch-up stitches*

Factor	Coefficient ± SE	*P* value	Reliability (%)†
Higher likelihood of having figure-of-8 hitch-up stitches			
Endocarditis	1.6 ± 0.62	.01	61
Higher ejection fraction‡	−2.2 ± 0.88	.01	70
Higher hematocrit§	−2.3 ± 0.61	.0002	73
Higher creatinine‖	0.52 ± 0.21	.01	70
Cabrol suture	1.8 ± 0.22	<.0001	100
Division of fused cusp raphe	1.3 ± 0.27	<.0001	98
Ascending aorta procedure	1.3 ± 0.24	<.0001	99
Recent date of surgery			84
Date of surgery	−0.70 ± 0.12	<.0001	
Date of surgery¶	9.4 ± 1.4	<.0001	
Higher likelihood of having no-figure-of-8 hitch-up stitches			
Prior cardiac surgery	0.92 ± 0.39	.02	61
Peripheral artery disease	1.3 ± 0.56	.02	56
Higher aortic valve regurgitation	0.33 ± 0.10	.001	53
Aortic arch procedure	2.1 ± 0.43	<.0001	99
Cusp plication	9.44 ± 0.20	.02	60
Cusp debridement	2.2 ± 0.40	<.0001	100
Cusp resection suture	0.89 ± 0.33	.008	54
Valve-sparing root reimplantation	2.9 ± 0.39	<.0001	100

SE, Standard error. **C* statistic = 0.92. †Percent of times factor appeared in 1000 bootstrap analyses. ‡(50/left ventricular ejection fraction), inverse transformation. §(40/Hematocrit), inverse transformation. ‖(Creatinine)^2, squared transformation. ¶Log[interval from/1/200 to date of surgery], logarithmic transformation.

TABLE E2. Reasons for aortic valve reoperations after bicuspid aortic valve repair with figure-of-8 hitch-up stitches in the overall cohort (N = 367)

Reason	≤1 y (n = 9)	>1 y (n = 30)
Cusp tear	6 (67)	0 (0)
Cusp perforation	2 (22)	0 (0)
Cusp prolapse	0 (0)	10 (33)
Dilated anulus	0 (0)	1 (3.3)
Endocarditis	1 (11)	2 (6.7)
Natural progression	0 (0)	16 (53)
Unknown	0 (0)	1 (3.3)

Values are presented as n (%).