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ORIGINAL ARTICLE

The Influence of Choice of Surgical Procedure on Long-Term Survival After Cardiac Surgery

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Background There is some interest in long-term survival after various cardiac surgical strategies, including off-pump versus on-pump coronary artery surgery (CAG), mitral valve (MV) repair versus replacement, and aortic valve (AV) bioprosthetic versus mechanical replacement.

Methods We studied patients older than 49 years of age, recording risk factors and surgical details at the time of surgery. We classified procedures as: MV surgery with or without concurrent grafts or valves; AV surgery with or without concurrent CAG; or isolated CAG. Follow-up was through the state death register and state-wide hospital attendance records. Risk-adjusted survival was estimated using Cox proportional hazards. Observed survival was compared to the expected age- and sex- matched population survival.

Results During a median follow-up of 14.8 years 5,807 of 11,718 patients died. The difference between observed and expected survival varied between 3.4 years for AV surgery and 9.6 years for females undergoing MV surgery. The risk-adjusted mortality hazard rate after off-pump CAG was 0.93 (95% CI 0.8–1.0, p=0.84), MV repair 0.67 (95% CI 0.6–0.8, p<0.0001), MV bioprosthesis 0.82 (95% CI 0.81 (0.6–1.0, p=0.11) and bioprosthetic AV replacement 1.02 (95% CI 0.9–1.2, p=0.82).

Conclusions Compared to the general population, cardiac surgical patients have a shorter than expected life expectancy. We observed a survival benefit of mitral valve repair over replacement. We did not observe significant survival differences between off-pump and on-pump CAG, nor between bioprosthetic and mechanical replacement.

Keywords Long-term survival • Cardiac surgery

Introduction

There have been extensive publications regarding the short- and intermediate-term outcomes following cardiac surgery. However, there have been fewer reporting long-term outcomes, and these have reported variable results. Loss of patients to follow-up is one of the issues affecting the

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accuracy of accurate long-term follow-up data. In Western Australia (WA), we have a relatively stable population that is geographically isolated (for example, it is more than 2,000 km to the next-nearest state capital or tertiary cardiac referral centre). In addition, since the early 1980s there has been a state-wide patient information system that records each interaction with WA public heath and also has record linkage to statutory death registries [1]. We have carefully recorded the risk factors and outcomes of patients undergoing cardiac surgery at our institutions and we took this relatively unique opportunity to re-examine the effects of choice of surgical procedure on long-term outcomes. The specific questions we wished to examine were: are there differences in long-term risk-adjusted outcome between patients having off-pump coronary artery surgery versus on-pump coronary artery surgery; having mitral valve repair versus mitral valve replacement; or having aortic valve bio-prosthetic valves versus mechanical prosthetic valves? Although our data was analysed retrospectively, we set these questions prior to performing any analysis in order to improve the validity of our findings.

Methods

Institutional approval was obtained for data collection through quality improvement activities 1100 and 051121-1.

Inclusion criteria included consecutive patients between 1993 and 2016 at two metropolitan tertiary public cardiac units. Patients were included if they underwent isolated coronary artery bypass surgery (CAG group), open surgery to the mitral valve with or without concurrent coronary artery grafting or surgery to other cardiac valves (MVR group), or open surgery to the aortic valve with or without concurrent coronary artery grafting or tricuspid valve repair (AVR group). Patients undergoing other cardiac operations were excluded from analysis. The number of patients included and excluded is described in Figure 1. Patients were classified into groups according to their first operation at our institutions. Risk factors for long-term survival were recorded at the time of surgery. These included patient age, gender, body mass index (BMI), estimated preoperative creatinine clearance [2], a preoperative diagnosis of diabetes, hypertension or anaemia, the preoperative left ventricular function estimated from echocardiac or angiographic examination by a cardiologist, a history of previous sternotomy surgery, the number of coronary artery grafts, the occurrence of total arterial re-vascularisation, concurrent surgical procedures, and the patient's Indigenous status. This chose this set of risk factors because we have consistently recorded them since 1993 and they include factors that have been previously identified as important for long-term survival after cardiac surgery [3–5]. To determine if survival has changed over time, patients were classified into three arbitrary groups of approximately equal size: those undergoing surgery before April 1999, those between April 1999 and July 2006, and those after July 2006. There was no experimental control of surgical procedures. Off-pump coronary artery surgery was considered to be any coronary artery grafts without cardiopulmonary bypass. Valve treatment was classified as either repair, replacement with a bio-prosthesis, or replacement with a mechanical prosthesis. Valve repair was considered to be any valve resection, reconstruction, or sub-valvular reconstruction with or without an annuloplasty ring. Patient who had a mitral valve repair with a concurrent prosthetic aortic valve replacement were classified as a valve replacement, not as a repair.

Follow-up was completed in October 2018 using the WA Department of Health Patient Management system. This records all in-patient and outpatient hospital appointments throughout WA public health and in addition, records date of death by data linkage with the West Australian register of deaths. The date of death, or alternatively, the date of the most recent live interaction with WA health was recorded. For survival analysis, patient survival was censored at the most recent date of confirmed living interaction with WA Health.

Statistical Analysis

Normally distributed data is reported as mean and standard deviation, skewed data by median and interquartile range. There was a small amount of missing risk-factor data. No imputation was used for univariate reporting. To avoid data loss in multivariate analysis non-informative substitution was performed using median values. Median follow-up was estimated by reverse Kaplan Meier.

Patients were considered lost to follow-up if they were neither recorded as deceased nor had a recent living interaction with a WA public hospital. Many of these patients will be alive and healthy, but some will have deceased after travelling outside the state or after a change of name. Our survival analysis adjusts for this to some extent by censoring patients at their last living interaction with a WA public hospital. However to estimate the maximum effect of this missing information we calculated best-case and worst-case models. The worst-case model was calculated with the assumption that all patients who had not been followed up for more than 1,000 days had died on the day of their last interaction with WA health. The best-case model was calculated with the assumption that all patients who were not recorded as deceased were still living at the censor date of the study.

Risk-Adjusted Survival

Cox proportional hazards analysis was used to risk-adjust survival data. All variables were retained in the model, there was no stepwise regression used. The assumption of proportional hazards was checked by calculating linear regression of Shoenfeld residuals against time. The accuracy of data entry for date of birth, date of death, and last appointment was checked for a random sample of 50 subjects.

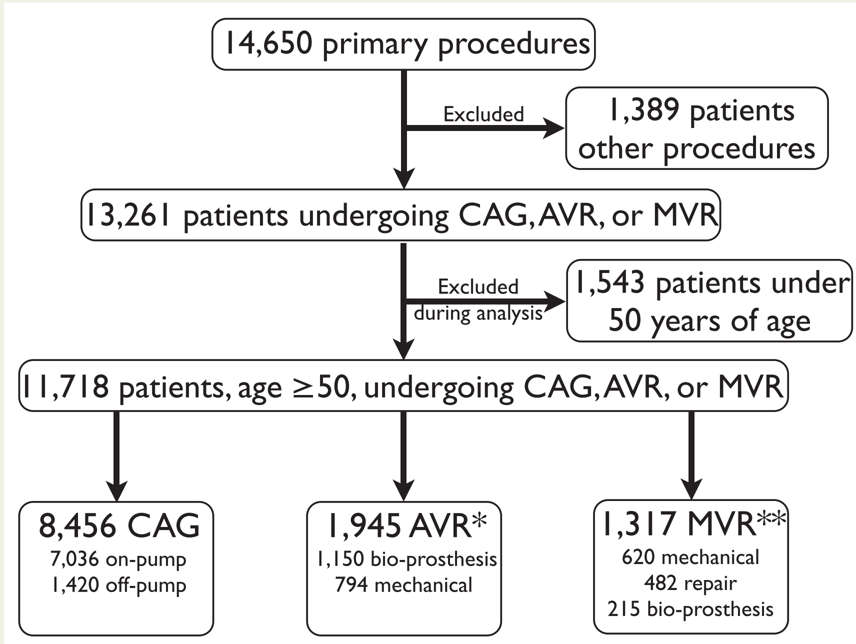

Figure 1 Patients included and excluded in the study. Patients were classified according to the first procedure undertaken at the study facility.
The 1,389 patients with "other procedures" include 562 ascending aortic replacements, 163 heart or lung transplants, 221 adult congenital procedures, 103 insertion of extracorporeal circulatory support, 38 tricuspid valve procedures, 83 pulmonary embolectomies, and 219 miscellaneous procedures, for example tumour excision or repair of acquired VSD.
* Includes 9 patients with concurrent tricuspid valve annuloplasty.
** Includes 188 patients with concurrent aortic valve replacement, 105 patients with a concurrent tricuspid valve repair, and 13 with treatment of both tricuspid and aortic valves. 60 patients had a mitral valve repair but were classified as mechanical (26) or bio-prosthesis (34) because of concurrent prosthetic insertion at the aortic valve.
Abbreviations: CAG, isolated coronary artery graft surgery; MVR, mitral valve surgery ± other procedures; AVR, aortic valve replacement ± coronary artery grafts or tricuspid valve repair.

Expected Survival

Age and sex matched expected survival was calculated using life-table analysis of death register aggregate data [6] for Western Australia between 1993 and 2015.

Power Calculation

Prior to performing any outcome analyses an estimate was made of the power to detect a clinically relevant effect for each hypothesis using cox proportional hazard regression. At this stage the approximate number of patients in each group was known, while risk-factor data was taken from a previous long-term survival study [7]. Assumptions included two-sided test with an alpha of 0.05, power of 80%, censor rate of 60%, and mean follow-up of 10 years (for CAG group) or 7 years (for MVR and AVR groups). For the off-pump hypothesis a relative risk of ±1.15 could be detected if 14% of CAG patients had off-pump surgery and the model R^2 is 0.039. For the AVR bio-prosthesis hypothesis a relative risk of ±1.21 could be detected if the proportion of patients with a bio-prosthesis was 55% with a R^2 of 0.22. For the MVR repair hypothesis a beta coefficient of ±1.26 could be detected if 36% of patients had a repair with a R^2 of 0.1.

Results

There were 13,261 patients who underwent CAG, AVR or MVR. The Kaplan-Meier survival curves for all patients categorised by age group are displayed in Figure 2. The assumption of proportional hazards did not hold for patients under 50 years of age, so these patients were excluded from further analysis. All the following results describe the remaining 11,718 patients who were 50 years of age or older at the time of surgery. There were 5,807 patients who deceased during the study. Median follow-up was 14.8 years. Seventy-five per cent (75%) of patients had either died or had a living interaction within 1.2 years of October 2018, 90% within 5.6 years, and 95% within 11.1 years.

Patient characteristics are described in Table 1.

The survival of patients over 50 years of age in the CAG, AVR and MVR groups is displayed graphically in Figure 3. At 20 years after surgery the overall mortality rate was 3.6% per year in the CAG group, 4.5% per year in the AVR group, and 3.9% per year in the MVR group. Median survival in the CAG group was 14.57 years (95%CI 14.3–14.9). In the AVR group median survival was 10.15 years (95% CI 9.8–10.6). In the MVR group median survival was 11.79 years (95% CI 10.9–12.6).

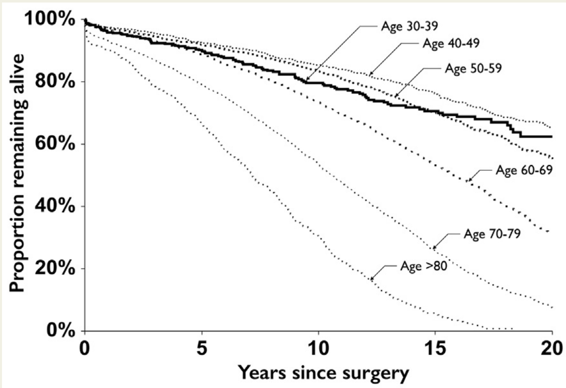

Figure 2 Kaplan-Meier survival curves for patients undergoing coronary artery surgery, aortic valve replacement or open mitral valve surgery categorised by age group.
This illustrates how the assumptions of proportional hazards are met for patients 50 years or older, but are violated for patients 30–39 years, and to a lesser extent, patients 40–49 years of age.

Risk factors for long-term survival in the CAG, AVR and MVR groups are shown in Table 2. The CAG model had 23 degrees of freedom, a log likelihood of -32,213 and R^2 was 0.21. The AVR model had 22 degrees of freedom, log likelihood of -7,146 and R^2 0.21. The MVR model had 22 degrees for freedom, log likelihood of -3,915 and R^2 0.26.

In the CAG group no statistically significant association was observed between risk adjusted long-term survival and off-pump surgery, although we cannot exclude relative risks between 0.8 and 1.0 (lower numbers indicating benefit to off-pump surgery). Statistically significant risk factors for reduced long-term survival were older age, male sex, impaired renal function, impaired LV function, anaemia, cerebrovascular disease, diabetes, and redo surgery. Hypertension and obesity were weak risk factors. The number of distal anastomoses and the use of total arterial revascularisation, compared to mixed arterial and venous grafting, were not associated with statistically significant associations with long-term survival.

Patients who had a mitral valve repair had a reduced risk of mortality, with a relative risk of 0.7, compared to those who had mitral surgery and received a mechanical prosthesis. Patients who underwent aortic valve replacement with a bio-prosthesis did not have significantly different risk adjusted survival compared to those who received a mechanical prosthesis, although we cannot exclude relative risks between 0.9 and 1.2 (lower numbers indicating benefit to bio-prosthesis). In both the AVR and MVR groups, the significant risk factors for long-term survival were similar to the CAG group with the exception that no significant association was observed with obesity, hypertension or cerebrovascular disease. Patients who required concurrent coronary artery surgery had reduced risk-adjusted survival.

In the AVR and MVR groups we did not observe any statistically significant changes to risk adjusted survival during the time periods encompassed by this study. In contrast, patients in the CAG group who had surgery between 1993 and 1999 had improved risk-adjusted long-term survival compared to those who had their surgery after 1999.

Although it was not part of our planned analysis, we repeated the survival models for the AVR and MVR groups after stratifying for age. Patients in the AVR group who were aged between 50 and 59 (n=261) had a relative risk of mortality of 1.35 (95% CIs 0.7–2.7) if they had a bio-prosthesis compared to a mechanical prosthesis. In the MVR group patients between 50 and 59 (n=325) had a relative risk of mortality of 0.88 (95% CI 0.5–1.6) if they had a repair, and 2.80 (95% CI 0.6–12.7) if they had a bio-prosthesis, both compared to a mechanical prosthesis.

Median survival, categorised by group and sex, is presented in Table 3 along with the expected population survival. Median patient survival was between 3.4 and 9.6 years shorter than expected. Females in the CAG and MVR groups had the greatest difference between observed and expected survival.

During the study we observed changes in the prevalence of risk factors, some indicating greater risk, some indicating lower risk. For example, in comparison to the 1993–99 group, patients undergoing CAG surgery between 2006 and 2016 were more likely to have a diagnosis of hypertension or diabetes, had a higher BMI, but also had higher creatinine clearance, were less likely to be female, and less likely to have a moderately- or severely-impaired left ventricle. The median age was 66 years in all time periods. Off-pump CAG surgery was uncommon before 1999, only 3% of CAG surgery patients had off-pump surgery before 1999, 30% of CAG patients had off-pump surgery between 1999 and 2006 and 21% after 2006. The Cox analysis was repeated after excluding patients who had surgery before 1999. The risk for off-pump CAG patients remained less than 1 (HR 0.96, 95% CI 0.86–1.08), while the increased risk for patients having surgery since 2006 persisted (HR 1.16, 95% CI 1.03–1.31).

In the CABG, AVR and MVR groups worst-case median survival (patients not seen for 1,000 days considered dead) was 12.1, 9.1, and 10.1 years respectively. Best-case median survival (all patients who were not recorded as dead considered to be alive at the time of analysis) was 16.2, 11.0, and 12.9 years respectively.

The random sample of patients that had data entry checked showed a mean error of 10 days per patient for duration of follow-up, no errors for date of death, and one patient with an incorrect date of birth.

Discussion

We have observed the risk of death during long-term follow-up of patients 50 years of age or older undergoing cardiac surgery is between 3.6% and 4.5% per year. The use of a mechanical prosthesis in the mitral position was associated

Table 1 Patient characteristics. Values are median with interquartile range, or proportion.

	CAG		AVR		MVR	
	n	Characteristic	n	Characteristic	n	Characteristic
Age	8,456	66.3 (59.4-72.5)	1,945	72.6 (65.3-78.0)	1,317	67.0 (60.0-73.7)
BMI	8,440	27.4 (24.8-30.4)	1,945	27.5 (24.4-30.8)	1,315	25.5 (22.8-28.7)
eCC ml.min/1.7 m^2	8,383	78.9 (61.8-95.3)	1,933	61.5 (47.6-76.3)	1,311	69.3 (50.8-86.9)
Male sex	6,657	78.7%	1,326	68.2%	768	58.3%
Indigenous status	243	4.1%	26	1.3%	36	2.7%
LV function						
Normal	4,519	54.5%	1,225	64.8%	820	63.7%
Mildly reduced	2,010	24.2%	287	15.2%	208	21.5%
Moderately reduced	1,237	14.9%	251	13.3%	169	14.3%
Severely reduced	529	6.4%	129	6.8%	90	6.5%
Preoperative diagnosis of						
Anaemia	1,649	19.5%	554	28.5%	405	30.8%
CVD	913	13.0%	211	10.8%	110	11.1%
Diabetes	2,283	27.1%	423	21.8%	226	17.2%
Hypertension	5,078	60.3%	1,082	55.8%	586	44.5%
Redo surgery	407	4.8%	127	6.5%	124	9.4%
Coronary artery grafts						
1-2	1,929	22.8%	532	27.4%	219	16.6%
3	2,991	35.4%	171	8.8%	91	6.9%
More than 3	3,535	41.8%	97	5.0%	80	6.1%
TAR	708	8.4%	122	6.3%	58	4.4%
Off-pump	1,420	16.8%	0	0%	0	0%
More than one valve	0	0%	9	0.5%	297	22.6%
Valve treatment						
Mechanical	0	0%	794	40.8%	620	47.1%
Repair	0	0%	0	0%	482	36.6%
Bioprosthesis	0	0%	1,151	59.2%	215	16.3%
Time period						
3/93-3/99	3,281	38.8%	484	24.9%	266	20.2%
4/99-7/06	2,649	31.3%	651	33.5%	474	36.0%
8/06-12/16	2,526	29.9%	810	41.7%	577	43.8%
Deceased	4,052	47.9%	1,115	57.3%	640	48.6%

Abbreviations: CAG, coronary artery group; AVR, aortic valve group; MVR, mitral valve group; BMI, body mass index; LV, left ventricle; CVD, cerebrovascular disease; TAR, total arterial revascularisation; Off-pump, off-pump coronary artery surgery; eCC, estimated creatinine clearance.

with reduced risk-adjusted long-term survival compared to mitral valve repair. We did not observe reduced risk-adjusted long-term survival in patients who underwent off-pump coronary artery surgery, nor did we observe any significant difference in risk-adjusted long term survival between patients who had a bio-prosthesis rather than a mechanical prosthesis in the aortic position, although our study did not have sufficient power to exclude higher risk-adjusted mortality in patients with bio-prostheses who were 50–59 years old, particularly in the mitral position.

To investigate our primary hypotheses it was necessary to record many other potential risk factors, which resulted in several interesting secondary observations. We did not observe any statistically significant survival trends in patients undergoing multiple distal coronary anastomoses compared to those who received only one or two, and we did not observe any risk-adjusted survival benefit from total arterial re-vascularisation. A priori, we felt it necessary to adjust for the time period that surgery took place because we speculated that patients undergoing surgery in recent years might show improved risk-adjusted survival. We were surprised to observe CAG patients who had surgery since 2006 had an increased risk of mortality compared to those undergoing surgery before 1999. This observation is difficult to interpret. The risk-factor profile of patients changed during the study, but not in a consistently adverse direction, and the mutivariate analysis should account for differences in risk factors. The most profound difference was the limited use of off-pump surgery before 1999. This could potentially confound the analysis, but our findings changed little after

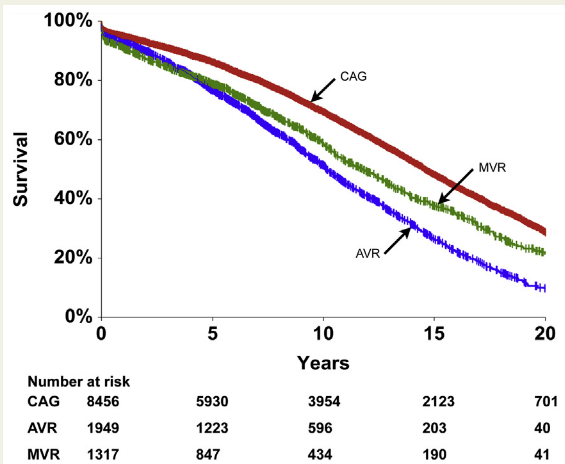

Figure 3 Kaplan-Meier survival for patients over 49 years of age, categorised by surgical group.
Abbreviations: CAG, coronary artery surgery group; MVR, mitral valve surgery group; AVR, aortic valve surgery group.
Vertical tick marks indicate censored observation.

excluding patients who underwent CAG surgery before 1999. Regardless, this is a post-hoc observation, and should be considered as a hypothesis-generating observation that requires confirmation in a study with that specific hypothesis.

We also took the opportunity to compare our patient outcomes with the expected survival of an age and sex matched population. In each of the surgical groups survival was shorter than expected. On the one hand, it is a credit to modern medicine that serious heart disease should shorten life expectancy by a relatively small amount. On the other hand, it indicates that the treatment of severe heart disease still has room for improvement, particularly in female patients.

Strengths

Our study has several strengths. Over a long period of time we carefully recorded patient operative details and preoperative risk factors for long-term survival in a large number of consecutive patients undergoing cardiac surgery in a geographically isolated location with a comprehensive public health database. We used Cox proportional hazards analysis to adjust for these risk factors. Our hypotheses were determined before any analysis was made. We have strictly censored patient records at their last known living interaction with our health system, to avoid doubts about the accuracy of our death registration.

Limitations

There are several limitations to our conclusions. Our study is observational and cannot have the scientific validity of a controlled experiment, but the existing randomised trials do not have large numbers of patients, so observational data may remain an important level of evidence. We excluded patients under 50 years of age because this age group had a different pattern of survival to the patients over 50 years of age, although only a small proportion of our patients were under 50 years of age. The model R^2 that we observed was between 0.21 and 0.26. This means that 75–80% of the variation in survival was not predicted by the risk factors recorded at the time of surgery. This is not unusual in studies of long-term survival, it reflects our limited ability to predict mortal illness. We recognise that there are additional risk factors that we could have recorded, for example, smoking history, the diagnosis of significant respiratory disease, the presence of abdominal obesity, the patient's compliance with medications and dietary advice. We also recognise that we lack many details of operative technique that could plausibly have effects on long-term outcome, for example the experience of the surgeon, the completeness of re-vascularisation, the specific type of valve prosthesis, the technical details of the mitral valve repair, the details of the valve pathology. A small proportion of patients were missing from follow-up, which will increase the uncertainty of our findings—we have estimated that this introduces between ±0.9 and ±2.4 years of uncertainty to our estimate of median survival depending on the surgical procedure.

Each of the hypotheses considered in this manuscript have received considerable scientific attention through randomised controlled trials, observational studies and meta-analyses without developing a clear consensus.

On- vs Off-Pump Surgery

There have been multiple randomised trials of on- and off-pump surgery comparing survival at 5 years or more. In one study there was a long-term benefit for on-pump surgery [8], but others have not observed a statistically significant difference, although it is possible that all these trials were underpowered to reliably detect a clinically relevant difference [9–13]. Multiple meta-analyses have included data from risk-adjusted observational studies. One of the most recent included 60,405 patients from eight studies, and concluded a long-term survival benefit of on-pump surgery, estimating a 10% reduction in risk of mortality at 5 years, and 14% at 10 years [14]. Our study is not in keeping with this meta-analysis—the 95% confidence intervals of the relative risk that we observed, 0.8–1.0, implies that a beneficial effect of on-pump surgery is unlikely.

Repair vs Replacement of the Mitral Valve

There are randomised trials comparing repair with replacement of the mitral valve [15,16], but as yet, only 2-year survival has been reported [17]. Several meta-analyses have reported the results of observational studies with conclusions that depend on the cause of the mitral valve dysfunction. For example, Salmasi *et al.* concluded there was no difference in long-term survival between

Table 2 Risk factors for long-term survival in CAG, AVR and MVR groups. Data shows relative risk for mortality with 95% confidence intervals (Larger values indicate higher risk of mortality).

Risk Factor	CAG			AVR			MVR		
	RR	95% CI	P	RR	95% CI	P	RR	95% CI	P
Age years (comparison group is age 50-59 yr)									
60-69	1.58	1.4-1.7	<0.0001	1.42	1.1-1.9	0.01	2.18	1.7-2.8	<0.0001
70-79	3.03	2.7-3.4	<0.0001	2.39	1.8-3.2	<0.0001	3.55	2.7-4.8	<0.0001
>79	5.6	4.8-6.6	<0.0001	3.68	2.7-5.0	<0.0001	6.12	4.1-0.2	<0.0001
Male	1.21	1.1-1.3	<0.0001	1.09	1.0-1.2	0.22	1.12	1.0-1.3	0.17
Indigenous	1.17	0.9-1.5	0.18	1.44	0.9-2.4	0.15	1.76	1.1-2.8	0.016
BMI kg/m^2 (comparison group is BMI <24)									
24.1-26.9	0.92	0.8-1.0	0.06	1.16	1.0-1.4	0.10	1.06	0.9-1.3	0.58
27.0-29.9	0.88	0.8-1.0	0.009	1.15	1.0-1.4	0.13	0.94	0.7-1.2	0.60
>29.9	1.13	1.0-1.3	0.01	1.18	1.0-1.4	0.08	1.04	0.8-1.3	0.75
eCC mL/1.73 m^2/min	0.99	1.0-1.0	<0.0001	0.98	1.0-1.0	<0.0001	0.98	1.0-1.0	<0.0001
Left ventricular impairment (comparison group is normal LV function)									
Mild	1.16	1.1-1.3	0.001	1.16	1.0-1.4	0.08	1.08	0.9-1.4	0.48
Moderate	1.55	1.4-1.7	<0.0001	1.30	1.1-1.6	0.002	1.50	1.2-1.9	0.0004
Severe	2.17	1.9-2.5	<0.0001	1.61	1.3-2.0	<0.0001	1.31	1.0-1.8	0.08
Preoperative diagnosis of									
Anaemia	1.39	1.3-1.5	<0.0001	1.55	1.4-1.8	<0.0001	1.60	1.3-1.9	<0.0001
CVD	1.34	1.2-1.5	<0.0001	1.12	0.9-1.4	0.25	1.05	0.8-1.4	0.73
Diabetes	1.46	1.4-1.6	<0.0001	1.33	1.1-1.6	0.0003	1.63	1.3-2.0	<0.0001
HTN	1.10	1.0-1.1	0.007	1.03	0.9-1.2	0.62	1.22	1.0-1.5	0.04
Redo surgery	1.52	1.2-1.6	<0.0001	1.28	1.0-1.6	0.03	1.28	1.0-1.6	0.05
Surgery to more than one valve							1.17	1.0-1.4	0.12
Any CAGs				1.23	1.1-1.4	0.001	1.18	1.0-1.4	0.08
Number of coronary artery distal anastomoses (comparison is 1-2)									
3	1.00	0.9-1.1	0.92						
>3	1.03	0.9-1.1	0.48						
TAR	0.90	0.8-1.0	0.12						
Off-pump	0.93	0.8-1.0	0.84						
Valve treatment (comparison is mechanical valve)									
Repair							0.67	0.6-0.8	0.0001
Bioprosthesis				1.02	0.9-1.2	0.82	0.81	0.6-1.0	0.11
Time epoch (comparison group is 3/93–3/99)									
4/99-7/06	1.17	1.1-1.3	0.0001	1.11	1.0-1.3	0.17	0.99	0.8-1.2	0.93
8/06-12/16	1.22	1.1-1.4	0.0008	0.99	0.8-1.2	0.86	0.90	0.7-1.2	0.42

Abbreviations: CAG, coronary artery group; AVR, aortic valve group; MVR, mitral valve group; BMI, body mass index; eCC, estimated creatinine clearance; CVD, cerebrovascular disease; HTN, systemic hypertension; TAR, total arterial revascularisation.

mitral valve repair and replacement [18] in patients with ischaemic mitral regurgitation, and MacHaalany *et al.* concluded that "5 and 10 year survival was significantly better with mitral valve repair" in patients who underwent surgery for mitral valve prolapse [19]. The present study supports a statistically significant and clinically important association between mitral valve repair and long-term survival, but is not sufficiently powered to determine if this is also true for the subgroup of patients with ischaemic mitral valve disease.

Bioprosthetic vs Mechanical Replacement of the Aortic Valve

Long-term survival after randomising patients to aortic valve replacement with either a bio-prosthesis or a mechanical valve has been reported in two trials [20,21]. One trial concluded that there was no difference in survival at 20 years [21], and the other observed superior survival at 15 years in patients given a mechanical valve [20]. A meta-analysis of 32 observational studies with 17,439 patients comparing risk-

Table 3 Expected survival of age and sex matched patients compared with observed survival categorised by surgical group and sex.

	Median Survival, years				
	Expected	95% CI	Observed	95% CI	Difference
CAG, Female	19.60	18.7-19.6	14.04	13.5-14.5	5.6
CAG, Male	18.62	17.8-18.6	14.81	14.5-15.1	3.8
AVR, Female	13.50	13.5-14.3	10.11	9.4-10.7	3.4
AVR, Male	13.64	12.9-14.4	10.21	9.5-10.8	3.4
MVR, Female	20.52	18.7-21.4	10.88	10.2-12.0	9.6
MVR, Male	17.75	16.9-18.6	12.47	11.3-13.4	5.2

Abbreviations: CAG, coronary artery surgery group; AVR, aortic valve surgery group; MVR, mitral valve surgery group.

adjusted long-term survival after either mechanical or bio-prosthetic aortic valve concluded that there was no difference in the overall death rate between patients receiving either mechanical or bio-prosthetic aortic valves irrespective of age [22]. Another included 22 observational studies with 13,281 patients and found a life expectancy crossover point at 59 years of age, and concluded that the currently recommended age threshold for implanting a bio-prosthesis could be lowered further [23]. More recently, two large risk-adjusted observational studies that included 307,045 Medicare patients over 65 years of age [24] concluded that their findings "underscore the potential benefits and lack of harm in using bio-prosthetic valves in older patients …" and a study that included 39,199 patients from the Society of Thoracic Surgeons database [25] concluded "… long term mortality rates are similar for those who received bio-prosthetic versus mechanical valves". The present study supports a clinically insignificant difference in survival between mechanical and biological prostheses in elderly patients.

Our study may provide useful information to advise patients 50 years of age and older about the long-term results of cardiac surgery, and may be of interest to health authorities, cardiologists and cardiothoracic surgeons. Life expectancy after cardiac surgery is reduced compared to the general population, particularly in female patients undergoing mitral valve surgery, but patients can typically expect more than a decade of survival depending on their age and general health. Patients who undergo off-pump coronary artery surgery in our study can be reassured that we have not seen evidence of reduced survival. Patients who have mechanical or bioprosthetic aortic and mitral valves implanted can be reassured that we have not observed any effect of the choice of valve on long-term survival. We can confidently advise patients who have mitral valve disease amenable to repair that this therapeutic approach is associated with better long-term survival than mitral valve replacement.

In conclusion, we have measured survival in patients over 50 years of age who have undergone a variety of cardiac surgical procedures over two decades. We have observed an association between mitral valve repair and longer survival, but we did not observe any association between long-term survival and with the choice between on-pump or off-pump coronary artery grafting, or the choice between biological or mechanical valve replacement in either the aortic or mitral positions.

Conflicts of Interest

No author declares a conflict of interest.

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