Surgical Aortic Arch Intervention at the time of Extended Ascending Aortic Replacement is Associated with Increased Mortality

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Abstract

Objective: To compare outcomes of hemiarch versus total arch repair during extended ascending aortic replacement. Methods: Between 2004 and 2017, 261 patients underwent hemiarch (n=149, 57%) or total arch repair (aortic debranching or Carrell patch technique, n=112, 43%) in the setting of extended replacement of the ascending aorta. Median follow-up was 17.2 (IQR 4.2–39.1) months. Multivariable models considering preoperative and intraoperative factors associated with mortality and aortic reintervention were constructed. Results: Survival was 89.0, 81.3, and 73.5% vs. 76.4, 69.5, and 61.7% at 1, 3, and 5 years in the hemiarch versus total arch groups, respectively (log-rank p=0.010). After adjustment for preoperative and intraoperative factors, the presence of a total arch repair (adjusted HR 2.53, 95% CI 1.39 – 4.62, p=0.003), and increasing age (adjusted HR per 10 years of age, 1.76, 95% CI 1.37 – 2.28, p<0.001) were associated with increased mortality. The cumulative incidence of aortic reintervention with death as a competing outcome was 2.6, 2.6, and 4.4% and 5.0, 10.3, and 11.9% in the hemiarch and total arch groups, respectively. After adjustment, the presence of a total arch repair was significantly associated with need for aortic reintervention (SHR 3.21, 95% CI 1.01 – 10.2, p=0.047). Conclusions: Overall survival after aortic arch repair in the setting of extended ascending aortic replacement is excellent, however, total arch repair and increasing age are associated with higher mortality and reintervention rates. A conservative approach to aortic arch repair can be prudent, especially in those of advanced age.

Introduction

The optimal approach to aortic arch repair in the setting of ascending aortic disease remains controversial and continues to evolve, especially in the setting of acute aortic dissection. While some advocate for replacement of the entire aortic arch during extended replacement of the ascending aorta[1-3], others restrict aortic arch repair to those settings in which aortic pathology exists[4-6]. Proponents of the former approach argue that a more aggressive approach to the aortic arch prevents the need for subsequent reintervention and potentially leads to better long-term outcomes. Others argue that absent aortic arch pathology, total arch replacement is associated with increased morbidity and mortality and may not decrease the need for further aortic reintervention or result in improved long-term survival.

Our custom has been to perform a hemiarch operation whenever possible, as long as it fully addresses the indication for operation. Total arch replacements are reserved for aortic dissections with tears in the arch, or aneurysms and other aortic arch pathology that involve the aortic branches. This study compares our results with hemiarch vs. total arch replacements in 261 consecutive operations for primary ascending aortic pathology with the objective to identify preoperative and operative factors associated with mortality and need for aortic reintervention.

Methods

Study Population and Definitions

This was a systematic retrospective cohort study of patients undergoing surgical aortic arch intervention in the setting of extended ascending aortic pathology at our institution between March 2004 and August 2017. Patients who underwent isolated ascending aortic replacement with a closed distal anastomosis were excluded. The Institutional Review Board of the University of Southern California Health Sciences Campus approved this study (HS-17-00621) and waived the requirement for patient consent.

Patients baseline demographics, operative characteristics, and perioperative outcomes were identified through our research database. The primary endpoints were mortality and need for aortic reintervention. All medical records from our electronic medical record system were reviewed. Postoperative complications were defined according to standard guidelines. [7] All variables are defined in**Supplemental Table 1** . Indication for surgery was divided into dissection, aneurysm, and "other". The dissection category included acute and chronic dissection, while the aneurysm category included both primary aneurysms and pseudoaneurysms. The "other" category included infections, porcelain aortas, and aorto-esophageal fistulas. Follow up was considered complete as of the date of last contact.

The entire cohort was divided into two categories based on type of surgical aortic arch repair. Hemiarch repair was defined as replacement of the undersurface of the aortic arch, without aortic arch vessel reconstruction. Total arch repair was defined as the need for re-implantation of aortic arch vessels either as a contiguous patch (i.e. Carrel technique) or the need for prosthetic aortic arch vessel debranching. We also included 4 cases where only the innominate artery was reimplanted because of the similar complexity of that procedure. Patients undergoing both emergent/urgent and elective procedures were included as well as patients with concomitant cardiac procedures.

Operative technique

Our approach to aortic dissection repair has been previously described[4,8]. For both hemiarch and total arch repairs, we prefer axillary artery cannulation with antegrade cerebral perfusion with mild to moderate hypothermia depending on extent of anticipated repair. In general, we cool to 27°C for hemiarch repair and 24 to 22°C for total arch repair. The decision to proceed with hemiarch versus total arch is made based on presence or absence of aortic arch pathology (dissection with intimal tear, aneurysm, infection).

Statistical Analysis

Statistical analyses were performed using STATA Version 15 (Statistical Software, College Station, TX) and R version 3.4.3 (https://www.R-project.org/). Preoperative and operative characteristics and postoperative outcomes were summarized. For continuous variables, comparisons between groups were conducted based on normality with either a two-sample independent t-test or Wilcoxon rank sum test. Categorical comparisons were by Chi square or Fisher's exact tests. Overall survival analyses were conducted by Kaplan-Meier methods, with log-rank comparison between surgical treatment groups. Cox proportional hazard modeling was conducted to identify pre and intraoperative factors associated with overall mortality. All variables with a univariable p value <0.2 were considered in creating a multivariable Cox proportional hazard model of overall mortality. The independent variable of interest was type of aortic arch repair (hemiarch versus total arch). Model diagnostics included use of Schoenfeld residuals to examine the proportional hazard assumption, martingale residuals to assess linearity, and Cox-Snell residuals to examine overall model fit. Influential observations were identified through use of delta beta and likelihood displacement. The proportional hazard assumption was found to be violated by the "other" category of surgical indication, therefore the final multivariable model is stratified by this covariate. A sensitivity analysis excluding key influential observations, and a separate analysis excluding the "other" category of surgical indication, confirmed the primary findings (see supplemental material). Results are presented as hazard ratio (HR) and 95% confidence intervals. Non-parametric estimates of the cumulative incidence of aortic reintervention were calculated[9]. Statistical analyses of need for aortic reintervention used competing risks and considered death as a competing outcome and are presented as sub-hazard ratios (SHR) and 95% confidence intervals[10]. Statistics with a two-sided p value less than 0.05 were considered statistically significant.

Results

Patient Characteristics and perioperative outcomes for overall cohort

A total of 261 patients are included in this study, of which 149 (57%) underwent hemiarch and 112 (43%) underwent total arch repair. Preoperative and operative characteristics are shown in **Tables 1 and 2** . In the overall cohort, median age was 60.6 (IQR 52.7 – 70.0) with a predominance of males, smokers, and those with hypertension. Acute aortic dissection was the predominant indication for surgery (66.3%). Those undergoing hemiarch and total arch repair were of similar age and body mass index (BMI), and had similar frequencies of hyperlipidemia, chronic obstructive pulmonary disease, chronic dialysis, previous stroke, and history of heart failure. Those undergoing hemiarch repair were more likely to be males, have hypertension, diabetes, peripheral artery disease, a prior myocardial infarction, and dissection as the operative indication.

Operative characteristics are notable for a similar proportion of reoperative surgery in both groups (35.7 vs. 25.7%, p=0.16, total arch vs. hemiarch). Type of proximal aortic repair was likewise similar in both groups with relatively equal distribution of isolated aortic replacement (at sinotubular junction), aortic replacement with aortic valve replacement, and aortic root replacement. Those undergoing hemiarch replacement were more likely to have an urgent/emergent operative indication and to have shorter cardiopulmonary bypass, aortic cross clamp, and antegrade cerebral perfusion times. Cerebral protection was used with similar frequency in both groups, with axillary cannulation and antegrade cerebral perfusion predominating in our recent series. Thirty-one (11.9%) of those undergoing total arch replacement had and elephant trunk.

In-hospital and 30-day mortality were significantly higher in those undergoing total arch replacement. In-hospital mortality was 5.4% in the hemiarch group versus 13.4% in the total arch group (P=0.024). 30-day mortality was 4.7% in the hemiarch group versus 14.3% in the total arch group (p=0.018). Vocal cord paralysis was more common in the total arch group, while other perioperative outcomes (use of ECMO, stroke, paraplegia, reoperation for bleeding, pneumonia, open chest) were similar between groups.

Overall Survival and Risk Factors for Mortality Analysis

Median follow-up was 17.2 months (IQR 4.2 – 39.1). Overall survival based on Kaplan-Meier estimates was 83.6, 76.2, and 68.2% at 1, 3, and 5 years, respectively (**Figure 1A and Appendix Table 2)** . Survival for those undergoing hemiarch repair was 89.0, 81.2, and 73.5% at 1, 3, and 5 years while survival for those undergoing total arch repair was 76.4, 69.5, and 61.7% at 1, 3, and 5 years (log rank p=0.010, **Figure 1B and Appendix Table 2**).

Analysis of Pre and Perioperative Factors Associated with Mortality

To assess the effect of type of aortic repair on overall mortality, a multivariable Cox proportional hazard model of pre and intraoperative factors was built (**Figure 2 and Appendix Table 3)** . Adjustments were made for age, gender, presence of antegrade cerebral perfusion, prior myocardial infarction, preoperative renal failure, peripheral artery disease, chronic lung disease, hyperlipidemia, hypertension, and concomitant coronary artery bypass grafting, the presence of a total arch repair was associated with a 2.53 time increase in mortality (HR 2.53, 95% CI 1.38 – 4.62, p = 0.003) as compared to a hemiarch repair. The other strong predictor of mortality in this analysis was increasing age, with a 1.76 time increase per 10 years of age (HR 1.76, 95% CI 1.37 – 2.28, p<0.001). Testing for an interaction between age and type of aortic repair was not statistically significant. While the other factors were not significant, they were left in the final model due to their level of significance on univariable analysis and clinical plausibility as a confounder. However, removal of each non-significant covariate did not alter the overall assessment of the relationship of either type of aortic arch repair or age in relationship to mortality. Predicted survival curves demonstrating the strong relationship with mortality between type of aortic repair (total arch or hemiarch) and age are shown in **Figure 3** .

Aortic Reintervention

The cumulative incidence of the need for aortic reintervention with death as a competing outcome is shown in **Figure 4** . Fourteen patients underwent aortic reintervention (4 hemiarch, 10 total arch). The median time to aortic reintervention was 505 days (IQR 152 – 505) days in the hemiarch group and 437.4 days (IQR 84 – 437.5) in the total arch group. Of the hemiarch reintervention, 2 required a descending thoracic endograft, 1 aortic valve replacement, and 1 re-replacement of the ascending aorta. Of the aortic reintervention in the total arch group, 7 required a descending thoracic endograft, 2 of which included aortic arch endografts, 2 open aortic arch repairs, and 1 aortic root replacement. The cumulative incidence of aortic reintervention with death as a competing outcome was 2.6, 2.6, and 4.4% at 1, 2, and 3 years in the hemiarch group and 5.0, 10.3, and 11.9% in the total arch group. The total arch group was 3.19 times more likely to require aortic reintervention (sub-hazard ratio (SHR) 3.10, 95% CI 1.00 – 10.1, p=0.049) in a univariable competing risk model (death as competing outcome). After adjustment for age, the presence of a total arch repair remained significantly associated with need for aortic reintervention (SHR 3.21, 95% CI 1.01 – 10.2, p=0.047). Age was not associated with the need for aortic reintervention (SHR 0.90, 95% CI 0.65 – 1.23, p=0.50).

Discussion

Operations in the setting of extended ascending aortic replacement can range in complexity from hemiarch to total arch replacement. The proponents of the hemiarch repair cite its technical simplicity, perceived durability, shorter circulatory arrest times, and potential for lower morbidity[11,12]. Those who prefer the total arch repair believe that the reintervention rate should be lower with complete replacement leading to improved long-term survival[13-15].

There are two principle findings of this study. The first is that, total arch replacement at the time of extended ascending aortic replacement is associated with increased mortality and reintervention rates when compared with hemiarch replacement. Second, age is associated with increasing mortality regardless of the extent of repair. Collectively, our data suggests that mortality and reintervention rates are higher in the total arch group, making the hemiarch procedure the preferred procedure as long as it adequately addresses the aortic pathology, especially in those of advanced age.

The baseline characteristics of those undergoing hemiarch and total arch replacement were somewhat different in this series. Those undergoing hemiarch replacement were more commonly male, hypertensive, diabetic, had peripheral arterial disease and a prior myocardial infarction. In addition, those undergoing hemiarch repair were more likely to have been done emergently and have an aortic dissection as opposed to an aortic aneurysm as the operative indication. Our assessment is that the hemiarch group in this study appeared somewhat "sicker" than the total arch group, and that would be consistent with our philosophy of only performing a total arch replacement during extended ascending aortic replacement when clinically indicated.

Our in-hospital and 30 day mortality was 5.4 and 4.7% in the hemiarch group and 13.4 and 14.3% in the total arch groups. These results, as well as our overall survival at 1, 3, and 5 years of 83.6, 76.2, and 68.2% are comparable to previously published studies[12,16-18]**.** While our study did not focus on perioperative outcomes, we had relatively low stroke rates (3.4 vs 5.4%, hemiarch vs total arch, p=0.43), as well as similar rates of paraplegia, need for postoperative extracorporeal membrane oxygenation, and reoperations for bleeding between groups. These results are similar to others reported in the literature as well as rates of paraplegia[12,19-23].

The primary objective of this study was to analyze preoperative and intraoperative factors which may be associated with survival in the setting of aortic arch surgery at the time of extended ascending aortic replacement. By Kaplan-Meier estimates, there was a clear difference in survival between those undergoing a hemiarch versus a total arch repair (log-rank p=0.012). To examine this relationship further, a multivariable Cox proportional hazard model was created which adjusted for baseline characteristics between groups. In this analysis, the presence of a total arch repair was associated with a 2.5 time increase in the likelihood of death during the follow up period as compared to the hemiarch group (HR 2.53, 95% CI 1.38-4.62, p=0.003). In addition to type of aortic repair, increasing age was also shown to be highly associated with mortality during the follow up period – with a 1.8 time increase per 10-year increase in age (HR 1.76 per 10 years of age, 95% CI 1.37-2.28, $p<0.001$). Other factors of significance or borderline significance on univariable modeling were not associated with mortality on multivariable modeling (gender, use of antegrade cerebral perfusion, previous myocardial infarction, renal failure, chronic lung disease, peripheral arterial disease, hyperlipidemia, hypertension, and concomitant coronary artery bypass grafting). It is also notable that the effect of age was constant in both the hemiarch and total arch groups, as assessment of an interaction term was not significant.

The central figure of this manuscript (Figure 3) demonstrates the powerful effect of type of repair and age. This figure puts the impact of the age and type of aortic repair estimates on mortality in perspective based on our multivariable model. The predicted hazard for mortality for a 50-year-old undergoing a hemiarch repair is 17.1 (HR 17.1, 95% CI 4.8 – 61.5), while the predicted hazard for mortality for a 70-year-old undergoing the same repair is 53.3 (HR 53.3, 95% CI 18.9 – 319.4). Similarly, the predicted hazard for mortality for a 50-year-old undergoing a total arch repair is 43.4 (HR 43.3, 95% CI 10-181), while the predicted hazard for mortality for a 70-year-old undergoing the same repair is 134.9 (HR 134.9, 95% CI 20-909). One can also compare across repair types – in a 50-year-old the hazard was 17.1 for a hemiarch and 43.4 for a total arch, and in a 70-year-old, the hazard was 53.3 with a hemiarch and 134.9 with a total arch.

It was not our intention in this study to examine indication in detail as we wanted to look at a comprehensive aortic experience in the setting of extended ascending aorta replacement. However, indication is known to be a strong risk factor for mortality in other studies[17,22] and was included in our multivariable modeling. While Indication was not associated with overall survival in this analysis, this variable violated the proportionality assumptions of Cox proportional hazard modeling. Therefore, our final multivariable model referenced above was "stratified" by indication. However, to confirm our primary findings that age and type of repair were highly associated with mortality and that this was not influenced by indication, three sensitivity analyses were performed (Supplemental Table 4). As can be seen in Supplement Table 4, stratification by the indication variable in the model resulted in an improvement in model fit with a lower AIC and BIC as compared to the non-stratified model (AIC 562 to 448, BIC 608 to 487). The violation of proportionality occurred in the "other" indication for surgery (infections, porcelain aortas, and aorto-esophageal fistulas, n=16). As this group is admittedly a bit "unique" we performed the analysis excluding these observations, with similar finding for presence of a total arch repair and age per 10 years (both remained highly significant, and this model had worse fit than the indication stratified model). Finally, we fit our final model separately, in the cohorts only with aortic dissections and only with aneurysms, again with similar findings that total arch replacement and age per 10 years were both associated with increased mortality. Our findings on the effect of age on overall outcomes can be supported by recent literature publications[13,24].

Type of aortic arch repair at time of extended ascending aortic replacement is thought to influence the need for subsequent aortic reintervention[5,13,14,24,25]. In this study, we utilized competing risk with death as a competing risk to determine estimates of aortic reintervention rates. As one cannot definitively determine that those who died would not have needed aortic reintervention, considering death as a competing risk is appropriate. However, analyses of these type are a bit difficult to interpret in the context of the literature as the vast majority of studies have not utilized this methodology.

Despite a more extensive aortic repair, those undergoing total arch replacement at the time of extended ascending aorta replacement had markedly higher reintervention rates (2.6, 2.6, and 4.4% at 1, 2, and 3 years in the hemiarch group and 5.0, 10.3, and 11.9% in the total arch group). After adjustment for age (the other strong predictor in the mortality model), those with a total arch repair were 3.2 times as likely to need aortic reintervention as compared to the hemiarch group (SHR 3.21, 95% CI 1.01 – 10.2, p=0.047). Age itself was not associated with the need for aortic reintervention (SHR 0.90, 95% CI 0.65 – 1.23, p=0.50).

There are numerous limitations to this study. First, this study is subject to all the limitation of a retrospective, non-protocoled study. Second, while presence of a total arch repair and age were variables of significance, the lack of a factor as significant could be due to small sample size and a type II error. Third, we lack power to examine different types of aortic arch repair. Fourth, the lack of accurate anatomic data from preoperative and postoperative computed tomography imaging makes assessment of these variables as it relates to mortality or need for aortic reintervention impossible. Fifth, there is a potential third group of interest we did not include in this study – those who had non-extended ascending aortic replacements with an aortic cross clamp in place. Sixth, the difference in survival may be due to higher perioperative mortality in the total arch group despite appropriately modeling to assess the continued adjusted risk over time. Seventh, surgeon bias and preference largely dictated when to intervene on aortic arch in extended ascending aortic replacement and type of aortic arch repair chosen. Last, the limited number of endovascular interventions in this study make any assessment of this technology in our practice difficult, although it is being increasingly utilized.

The optimal approach to aortic arch repair in the setting of ascending aortic disease remains controversial and continues to evolve. While some advocate for extensive replacement of the aortic arch during extended replacement of the ascending aorta, others prefer a more tempered approach absent true pathology. While this study cannot directly compare the two philosophical approaches of aortic arch repair outlined above, as aortic arch repair was only performed in this study when clinically indicated, if addressing all aortic pathology present at the time of operation is adequate, we have might expect to see similar survival and reintervention rates between these two groups. On the other hand, if more isolated pathology only requiring hemiarch replacement of the aorta truly progresses, then one may see a higher reintervention and possibly mortality rate in the less aggressively managed "hemiarch" group. The fact we found higher rates of mortality and reintervention in the total arch group, when we only addressed the aortic arch when pathology was present suggests that this group represents a group of patients with disease distinct from those with isolated ascending aortic pathology and that those with arch pathology inherently have more advanced disease which is likely to both decrease survival and increase the need for further aortic reintervention. This effect was particularly prominent in those of advanced age.

In conclusion, our data suggests that mortality and reintervention rates are higher with total arch replacement in the setting of extended ascending aortic replacement, making the hemiarch procedure the preferred procedure as long as it adequately addresses the aortic pathology, especially in those of advanced age. The rationale for extending ascending aortic repair to include a total arch replacement in order to decrease reintervention may not be valid.

Author Contributions:

Concept/design: MB, RE, DL, RC, WM

Data collection: RE, DL, BA, KK

Data analysis/interpretation: MB, WM, RE

Drafting article: MB, RE, DL, BA, RC

Critical revision of article: MB, RC, VS

Approval of article: MB, RC, VS

Statistics: MB, RE, WM

Funding secured by: MB, VS

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Table 1. Preoperative characteristics[a]

Characteristic

Overall Cohort

(n = 261)

Total Arch

(n = 112)

Hemia Arch

(n = 149)

p value

Characteristic **Overall Cohort** (n = 261) **Total Arch** (n = 112) **Hemia Arch** (n = 149) **p value** Age, years (Q25, Q75) 60.6 (52.7, 70.0) 63.1 (53.4, 70.2) 59.5 (52.6, 69) 0.428 BMI, kg/m^2 ±SD 27.4 (24.4, 31.6) 27.3 (24, 29.8) 27.5 (24.4, 32.3) 0.258 Male, n (%) 181 (69.4) 68 (60.7) 113 (75.8) 0.009 Smoking History, n (%) 204 (78.2%) 93 (83.0%) 111 (74.5%) 0.098 Hypertension, n (%) 177 (67.8%) 66 (58.9%) 111 (74.5%) 0.008 Diabetes, n (%) 31 (11.9%) 8 (7.1%) 23 (15.4%) 0.040 Hyperlipidemia, n (%) 68 (26.1%) 25 (22.3%) 43 (28.9%) 0.234 Previous cardiac surgery, n (%) Preop chronic dialysis, n (%) 10 (3.8%) 4 (3.6%) 6 (4.0%) 0.850 Peripheral artery disease, n (%) 28 (10.7%) 7 (6.3%) 21 (14.1%) 0.043 Previous stroke, n (%) 20 (7.7%) 8 (7.1%) 12 (8.1%) 0.784 History of MI, n (%) 21 (8.1%) 3 (2.7%) 18 (12.1%) 0.006 Heart failure, n (%) 43 (16.5%) 17 (15.2%) 26 (17.5%) 0.624 Primary Indication <0.0001 Type A Dissection, n (%) 173 (66.3%) 60 (53.6%) 113 (75.8%) Aneurysm, n (%) 72 (27.6%) 46 (41.1%) 26 (17.5%) Other, n (%) 16 (6.1%) 6 (5.4%) 10 (6.7%)

[a] *Continuous variables are expressed as median and interquartile range; group differences tested with two-sample Wilcoxon rank sum test. Categorical variables are expressed as frequency (percent); group differences tested with Chi Square or Fisher's exact test.; Abbreviations: BMI - body mass index*

Table 2. Operative Characteristics[a]

Characteristic

Total

(n = 261)

Total Arch

(n = 112)

Hemiarch

(n = 149)

p value

Characteristic **Total** (n = 261) **Total Arch** (n = 112) **Hemiarch** (n = 149) **p value** Reoperative sternotomy 81 (31.0) 40 (35.7) 41 (27.5) 0.157 Emergent/urgent operation 205 (78.5) 76 (67.9) 129 (86.6) <0.0001 Proximal aortic repair 0.304 Isolated ascending 90 (34.5) 44 (39.3) 46 (30.9) Aortic valve replacement 96 (36.8) 42 (37.5) 54 (36.2) Aortic root replacement 68 (26.1) 23 (20.5) 45 (30.2) Valve sparing root replacement 7 (2.7) 3 (2.7) 4 (2.7) Concomitant CABG 37 (14.2) 15 (13.4) 22 (14.8) 0.753 Femoral artery 26 (10.0%) 13 (11.6%) 13 (8.7%) Deep hypothermic circulatory arrest (Y/N) 50 (19.22%) 20 (17.9%) 30 (20.1%) 0.644 Operative times (min) CPB time (min) 184 (145, 233) 213.5 (167, 282) 166 (140, 215) <0.0001 Aortic Cross-clamp time (min) 93.5 (67, 146) 110 (75, 170) 87 (61, 141) 0.0019 Antegrade cerebral perfusion time (min) 23 (17, 32) 30 (22, 46) 19 (14.5, 27) <0.0001 Deep hypothermic circulatory arrest (min) 11 (3, 19) 15.5 (6.5, 21.5) 9 (3, 15) 0.1088 Lowest core temperature (C) 26 (24, 28.4) 25 (23, 27.3) 27 (24.8, 28.7) 0.001 Era of operation 0.018 2004 – 2012 82 (31.4%) 44 (39.3%) 38 (25.5%) 2013 – 2017 179 (68.6%) 68 (60.7%) 111 (74.5%)

[a] *Continuous variables are expressed as median and interquartile range; group differences tested with two-sample Wilcoxon rank sum test. Categorical variables are expressed as frequency (percent); group differences tested with Chi Square or Fisher's exact test. Abbreviations: CABG – Coronary artery bypass grafting*

[a] *Continuous variables are expressed as median and interquartile range; group differences tested with two-sample Wilcoxon rank sum test. Categorical variables are expressed as frequency (percent); group differences tested with Chi Square or Fisher's exact test.*

FIGURE LEGENDS:

Figure Legends

Figure 1. A) Kaplan-Meier survival estimate for overall survival for entire cohort of 261 patients with 95% confidence intervals. B) Kaplan-Meier analysis of survival stratified by type of aortic arch repair with 95% confidence intervals. Log-Rank comparison between strata 0.012.

Figure 2 . Forest plot of variables associated with overall mortality after multiple variable adjusted Cox-proportional hazard modeling (bars represent 95% confidence intervals).

Figure 3 . Cox proportional hazard survival estimates for hypothetical 40, 50, 60, and 70-year-old patient undergoing total arch and hemi arch replacement.

Figure 4. Non-parametric estimates of cumulative incidence of the probability of reoperation with death as a competing outcome for presence (dashed line) or absence (solid line) of any aortic reintervention. See Online Appendix Table 2 for confidence intervals.

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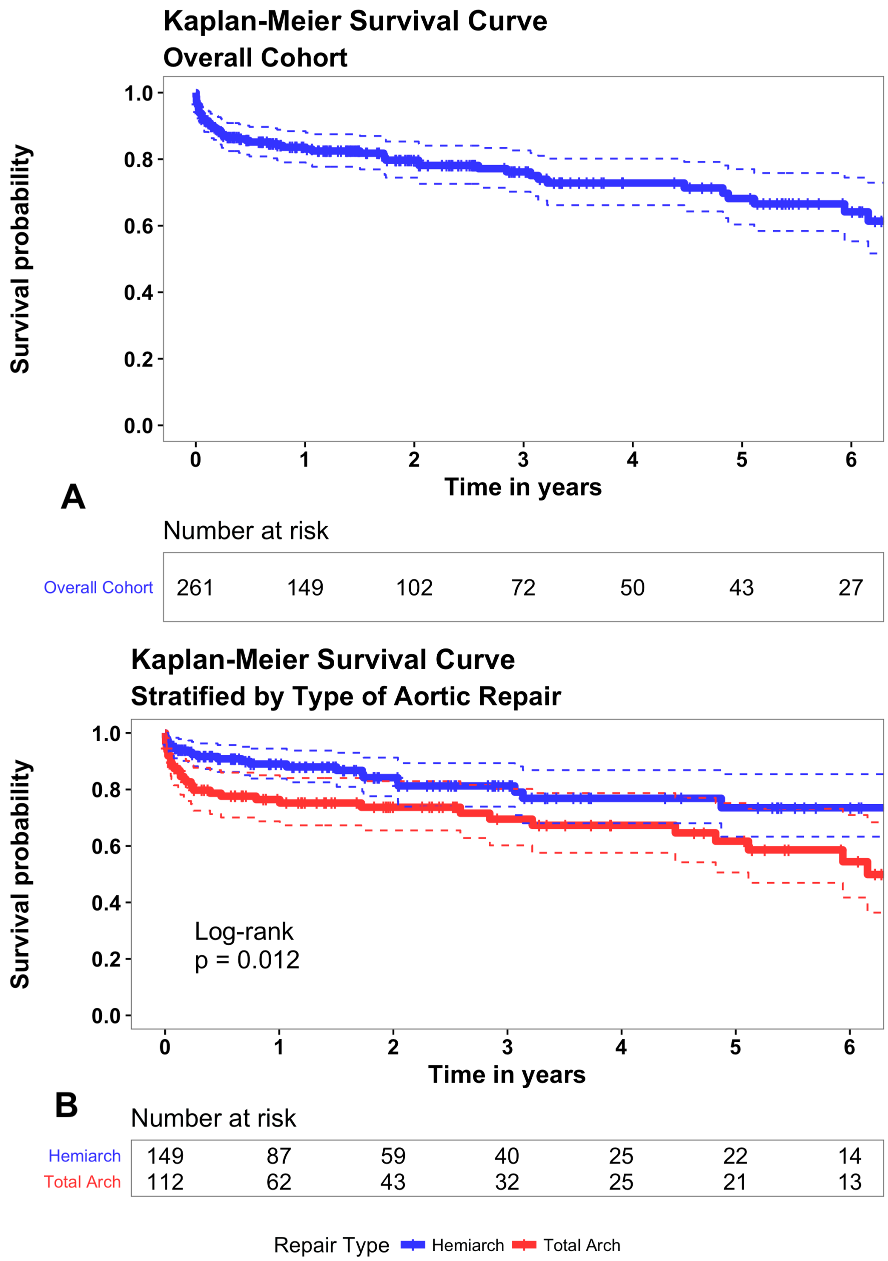
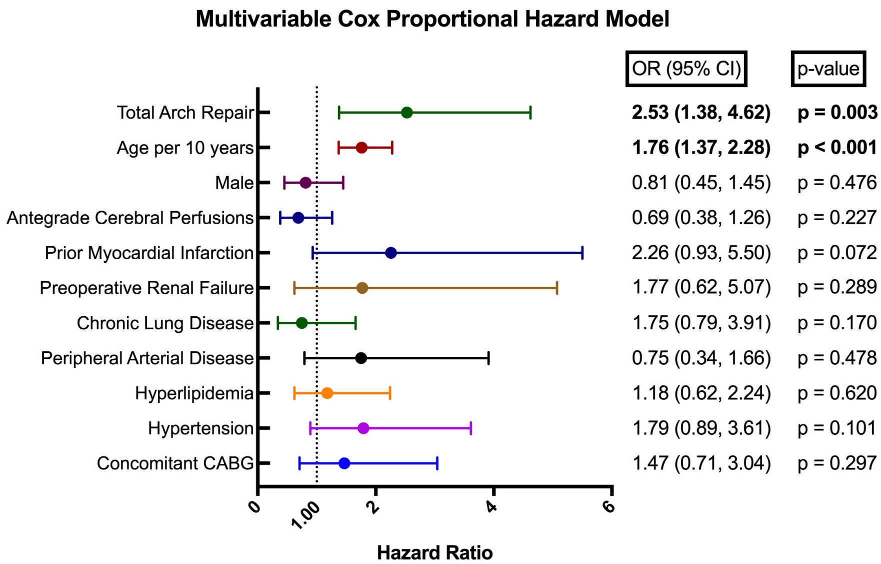
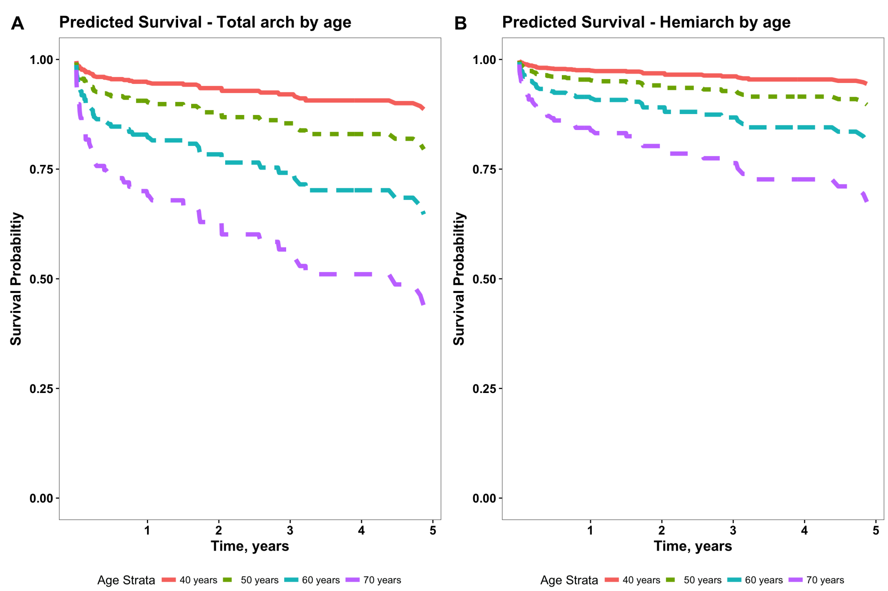
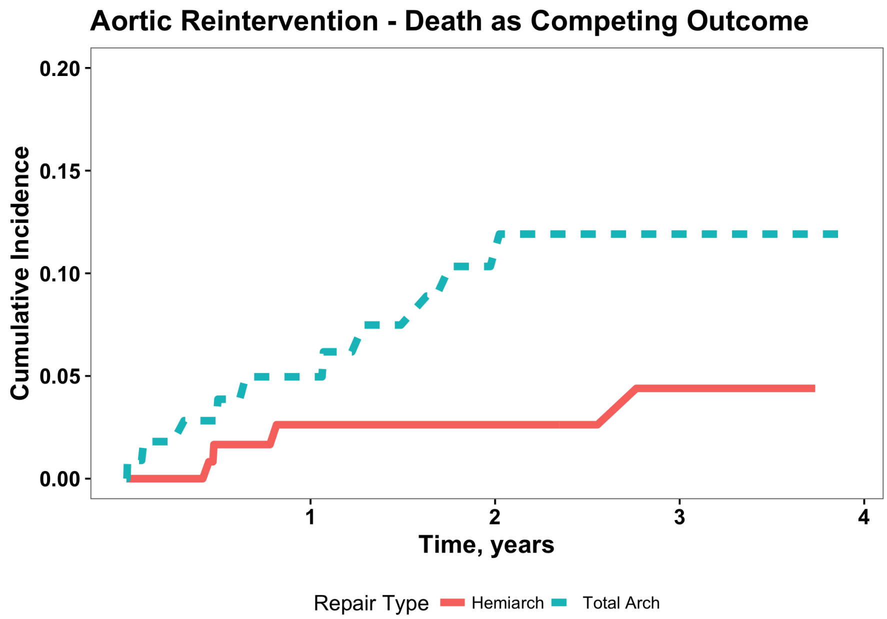

Kaplan-Meier Survival Curve
Overall Cohort
Survival probability
1.0
0.8
0.6
0.4
0.2
0.0
0 1 2 3 4 5 6
Time in years
A
Number at risk
Overall Cohort 261 149 102 72 50 43 27
Kaplan-Meier Survival Curve
Stratified by Type of Aortic Repair
Survival probability
Log-rank
p = 0.012
Time in years
B
Number at risk
Hemiarch 149 87 59 40 25 22 14
Total Arch 112 62 43 32 25 21 13
Repair Type Hemiarch Total Arch


Multivariable Cox Proportional Hazard Model
OR (95% CI)
p-value
Total Arch Repair
Age per 10 years
Male
Antegrade Cerebral Perfusions
Prior Myocardial Infarction
Preoperative Renal Failure
Chronic Lung Disease
Peripheral Arterial Disease
Hyperlipidemia
Hypertension
Concomitant CABG
2.53 (1.38, 4.62)
p = 0.003
1.76 (1.37, 2.28)
p < 0.001
0.81 (0.45, 1.45)
p = 0.476
0.69 (0.38, 1.26)
p = 0.227
2.26 (0.93, 5.50)
p = 0.072
1.77 (0.62, 5.07)
p = 0.289
1.75 (0.79, 3.91)
p = 0.170
0.75 (0.34, 1.66)
p = 0.478
1.18 (0.62, 2.24)
p = 0.620
1.79 (0.89, 3.61)
p = 0.101
1.47 (0.71, 3.04)
p = 0.297
0
1.00
2
4
6
Hazard Ratio


A
Predicted Survival - Total arch by age
B
Predicted Survival - Hemiarch by age
Survival Probabiltiy
1.00
0.75
0.50
0.25
0.00
1
2
3
4
5
Time, years
Age Strata
40 years
50 years
60 years
70 years


Aortic Reintervention - Death as Competing Outcome
Cumulative Incidence
0.20
0.15
0.10
0.05
0.00
1
2
3
4
Time, years
Repair Type
Hemiarch
Total Arch