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Article

A Novel Risk Score to Predict Thirty-Day Readmissions after Acute Type A Aortic Dissections

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Abstract

Background: Readmissions following acute type A aortic dissections (ATAAD) are associated with potentially worse clinical outcomes and increased hospital costs. Predicting which patients are at risk for readmission may guide patient management prior to discharge. **Methods**: The National Readmissions Database was utilized to identify patients treated for ATAAD between 2010 and 2018. Univariate mixed effects logistic regression was used to assess each variable. Variables were assigned risk points based off the bootstrapped (bias-corrected) odds ratio of the final variable model according to the Johnson's scoring system. A mixed effect logistic regression was run on the risk score (sum of risk points) and 30-day readmission. Calibration plots and predicted readmission curves were generated for model assessment. **Results**: A total of 30,727 type A aortic dissections were identified. The majority of ATAAD (66%) were in men with a median age of 61 years and 30-day readmission rate of 19.4%. The risk scores ranging from –1 to 14 mapped to readmission probabilities between 3.5% and 29% for ATAAD. The predictive model showed good calibration and receiver operator characteristics with an area under the curve (AUC) of 0.81. Being a resident of the hospital state (OR: 2.01 [1.64, 2.47], $p < 0.001$) was the highest contributor to readmissions followed by chronic kidney disease (1.35 [1.16, 1.56], $p = 0$), discharge to a short-term facility (1.31 [1.09, 1.57], $p = 0.003$), and developing a myocardial infarction (1.20 [1.00, 1.45], $p = 0.048$). **Conclusions**: The readmission model had good predictive capability given by the large AUC. Being a resident in the State of the index admission was the most significant contributor to readmission.

Keywords

aortic dissection; type A aortic dissection; aorta; NRD; HCUP

Introduction

Acute aortic dissection is a medical emergency with a reported incidence of 4.4 per 100,000 person-years [1]. Acute type A aortic dissection (ATAAD) is a high-acuity subtype with a pre-hospital mortality rate of 49% and an in-hospital mortality of 22%, and it warrants emergent surgical repair [2–4], as lack of prompt diagnosis and treatment could lead to complications such as aortic rupture, cardiac tamponade, malperfusion syndromes, and aortic valve insufficiency [5]. Surgical repair for ATAAD has resulted in declining mortality rates with advancing eras [6], and this highlights the need to review other outcome measures for the purpose of further reducing morbidity and mortality associated with ATAAD. One such metric for assessing outcomes after ATAAD is the 30-day readmission rate. This metric has been receiving greater attention since the launch of the Hospital Readmissions Reduction Program (HRRP) which was designed to curb the rising readmission rates that have a tremendous economic and clinical impact. Cardiovascular procedures have a reported 30-day readmission rate of approximately 29% [7]. In the context of aortic surgery, only a few studies have assessed readmissions. These studies mostly pertained to type B aortic dissections or thoracic endovascular aortic repair (TEVAR). As such, scarce data are available on the factors that impact readmission after ATAAD.

Therefore, we sought to analyze the 30-day readmission rates for all patients with a primary diagnosis of ATAAD using a national database and to identify its predictors using a novel predictive risk scoring system.

Methods

Data Source

We used the 2010–2018 Nationwide Readmissions Database (NRD), a publicly available database of allpayer hospital inpatient stays developed by the Agency for Healthcare Research and Quality as part of the Healthcare Cost and Utilization Project (HCUP). The NRD is drawn from the State Inpatient Databases that can be used to track a patient across hospitals within a State. The NRD also includes all discharge records of patients treated in US community hospitals, excluding rehabilitation and long-term acute care facilities.

Study Population and Baseline Characteristics

We used the International Classification of Diseases, Ninth (ICD9) and Tenth (ICD10) edition, Clinical Modification procedure codes (**Supplementary Table 1**) to identify all hospital admissions with type A Aortic Dissection in patients aged $\geq$18. We excluded index cases after November 30th and the admission with in-hospital mortality during index cases. Baseline patient characteristics, complications, and hospital-level characteristics were included. The Healthcare Cost and Utilization Project Clinical Classification Software (CCS) and ICD9 and 10 Clinical Modification codes were used to define these variables. Further details are provided in the supplementary material (**Supplementary Table 2**) and can also be found at HCUP website (https://hcup-us.ahrq.gov/db/nation/nrd/nrddde.jsp).

Outcomes

The primary endpoint was 30-day all-cause unplanned readmission. Readmissions were identified according to the methodology outlined by the Healthcare Cost and Utilization Project. For patients who had multiple readmissions, only the first readmission was included.

Statistical Analysis

Baseline characteristics, hospital-level characteristics, and in-hospital complications were compared between readmitted and non-readmitted patients using non-parametric testing. Categorical variables are expressed as percentages and continuous variables as mean $\pm$ standard deviation (SD) or median (interquartile range [IQR]) as appropriate.

Using hospitals as the random parameter, we conducted univariable mixed-effects logistic regression to assess each variable, to identify those with $p < 0.2$. We then included all variables found in the univariable analysis in a bootstrapped mixed-effects logistic regression with backward elimination to fit the final model. Variables found to be statistically significant were assigned risk points based on the bootstrapped (bias-corrected) odds ratio according to the Johnson's scoring system [8]. Area under the ROC curve (AUC), calibration plot, and predicted readmission plot were used to validate the regression model. Statistical analysis was performed with IBM SPSS Statistics 20.0 (IBM Corp, Armonk, NY, USA).

Results

Baseline Characteristics

A total of 30,727 type A aortic dissections were identified. Median patient age was 61 years (IQR 51–72) with females comprising 34% of the population. The discharge location was different between the groups with routine discharge being most common in the non-readmission group (42% *vs.* 37.5%, $p < 0.001$) and home healthcare slightly more common in the readmission group (30.7% *vs.* 31.2%). In terms of insurance, a greater proportion of patients in the readmission group were Medicare (46.8% *vs.* 42.9%, $p < 0.001$) and Medicaid (13.6% *vs.* 10.9%) beneficiaries. In contrast, a greater proportion of the non-readmission group either had private insurance (34.7% *vs.* 29.4%) or paid for themselves (6.6% *vs.* 5.4%).

Most patients were residents of the states in which they obtained treatment (94% in the non-readmission group *vs.* 87% in the readmission group, $p < 0.001$). At baseline, most patients (27%) belonged to the lowest income quartile or the 3rd income quartile (24%).

In terms of location, the majority of patients were in the "fringe" counties of metropolitan areas (non-readmission: 17.1% *vs.* readmission: 16.3%, $p < 0.001$). Further baseline and demographic details are presented in Table 1.

Clinical Outcomes

The overall rate of 30-day readmission in ATAAD patients was 19.4%. Myocardial infarction was the most prevalent (85.3%) complication and was observed with greater preponderance in the readmission cohort (86.5% *vs.* 85%, $p < 0.001$). Pneumonia (16.6% *vs.* 14.7%, $p < 0.001$), acute kidney injury (34.3% *vs.* 31.2%, $p < 0.001$), ileus (4.9% *vs.* 3.9%, $p < 0.001$), and sepsis (5.2% *vs.* 4%, $p < 0.001$) were also higher in incidence in the readmission cohort. Hemorrhage (43.5% *vs.* 45%, $p = 0.01$) was the only complication with lower incidence in the readmission cohort. Other complications such as heart failure, arrhythmia, bowel ischemia, *etc*., were similar between the groups. Further details are presented in Table 2.

Mixed-Effect Logistic Regression Analysis

The final variables that were incorporated into this model are shown in Table 3.

The factor with the highest odds ratio in the model was resident status of the patient (OR 2.01 [1.64–2.47], $p < 0.001$) with 6 risk points. Other statistically significant variables that increased the odds of readmission were hypertension (OR 1.18 [1.01–1.37], $p = 0.035$), chronic kidney disease (1.35 [1.16–1.56], $p = 0$), myocardial infarction (OR 1.2 [1.00–1.45], $p = 0.048$), and transfer to other skilled

Table 1. Baseline characteristics of all included patients.

Variable	Total	No readmission	Readmission	*p*-value
	N = 30,727	N = 24,756	N = 5971	
Age	61 (51–72)	61.00 (51–72)	61.00 (51–72)	0.75
Female	10,513 (34.22%)	8438 (34.08%)	2075 (34.76%)	0.33
Discharge Location				<0.001
Routine	12,640 (41.14%)	10,403 (42.02%)	2237 (37.47%)	
Short-term hospital	669 (2.18%)	558 (2.26%)	111 (1.85%)	
Other	7812 (25.43%)	6101 (24.65%)	1711 (28.65%)	
Home health care (HHC)	9455 (30.77%)	7590 (30.66%)	1865 (31.23%)	
Insurance				<0.001
Medicare	13,410 (43.64%)	10,616 (42.88%)	2794 (46.80%)	
Medicaid	3495 (11.37%)	2685 (10.85%)	809 (13.55%)	
Private	10,345 (33.67%)	8589 (34.69%)	1756 (29.41%)	
Self-pay	1956 (6.37%)	1636 (6.61%)	320 (5.37%)	
Other	1296 (4.22%)	1040 (4.20%)	256 (4.29%)	
Resident	27,105 (88.21%)	21,498 (86.84%)	5607 (93.90%)	<0.001
Total Charges × 1000	59.28 (40.24–88.82)	58.78 (39.76–88.61)	61.65 (42.51–90.16)	0.09
Median Household Income				0.01
Quartile 1	8281 (26.95%)	6604 (26.67%)	1678 (28.10%)	
Quartile 2	7298 (23.75%)	5844 (23.61%)	1454 (24.35%)	
Quartile 3	7466 (24.30%)	6099 (24.64%)	1366 (22.89%)	
Quartile 4	7130 (23.21%)	5751 (23.23%)	1379 (23.10%)	
Patient Location				<0.001
"Central" counties of metro areas	4870 (15.85%)	3902 (15.76%)	968 (16.22%)	
"Fringe" counties of metro areas	5205 (16.94%)	4230 (17.09%)	975 (16.32%)	
Metro areas: 250,000–999,999 people	4044 (13.16%)	3264 (13.19%)	780 (13.06%)	
Metro areas: 50,000–249,999 people	1824 (5.93%)	1503 (6.07%)	321 (5.37%)	

nursing or intermediate care facility (OR 1.31 [1.09–1.57], $p = 0.003$). Bleeding (OR 0.86 [0.76–0.98], $p = 0.026$) was significantly associated with reduced odds of readmission in the regression model. The regression model had an AUC of 0.81, and reasonable calibration. Risk scores that ranged from –1 to 14 mapped to readmission probabilities of 3.5 to 29% (Fig. 1).

Discussion

There is a paucity of data on readmission following ATAAD. The few studies on this topic largely address readmission after type B aortic dissection [7,9–11]. The present study presents a large patient population to help identify predictors of 30-day readmission in ATAAD using a nationwide database.

We found a 19.4% overall rate of 30-day readmission in our cohort. We also found that a lower number of the readmitted patients had been routinely discharged. Additionally, more of these patients were discharged to Home Healthcare Services (HHS) and other unspecified facilities. This requires further investigation as it might impact the interpretation of readmission rates. Furthermore, a greater number of patients in the readmission group were on Medicare and Medicaid insurance, while in the non-readmission group, more patients were either self-paying or had private insurance. This could indicate the impact of socioeconomic factors on health-related outcomes such as readmission rates. Further strengthening this inference is the fact that more readmitted patients belonged to the lower two income quartiles while more of the non-readmitted patients belonged to the top two income quartiles. As such, it could be surmised that there may be additional factors affecting outcomes which may not directly relate to the quality of patient care during index hospitalization. Moreover, patients in the readmission group had higher incidences of myocardial infarction (MI), pneumonia, acute kidney injury (AKI), ileus, and sepsis; however, they had a lower rate of hemorrhage compared to the non-readmission group. These results are not unexpected as ATAAD patients are a high-acuity cohort with concurrent risk factors for other disease processes.

We found the following factors to be associated with 30-day readmission: being a resident of the State in which treatment was sought, coronary artery disease (CAD), chronic kidney disease (CKD), MI, and transfer to other facilities such as skilled nursing and intermediate-care facilities. On the contrary, bleeding was negatively associated with 30-day readmission. Since bleeding following surgery

Table 2. Clinical outcomes following admission for acute type A aortic dissection.

Complications	Total	No readmission	Readmission	*p*-value
	N = 30,727	N = 24,756	N = 5971	
Myocardial Infarction	26,197 (85.26%)	21,033 (84.96%)	5163 (86.48%)	<0.001
Heart Failure	3815 (12.42%)	3072 (12.41%)	744 (12.46%)	0.91
Arrhythmia	12,221 (39.77%)	9867 (39.86%)	2354 (39.43%)	0.55
Pneumonia	4637 (15.09%)	3646 (14.73%)	991 (16.59%)	<0.001
Respiratory Failure	4310 (14.03%)	3495 (14.12%)	815 (13.66%)	0.36
Acute Kidney Injury	9774 (31.81%)	7726 (31.21%)	2048 (34.29%)	<0.001
Urinary Tract Infection	3311 (10.78%)	2659 (10.74%)	653 (10.93%)	0.67
Paraplegia	532 (1.73%)	424 (1.71%)	107 (1.80%)	0.64
Bowel Ischemia	679 (2.21%)	552 (2.23%)	128 (2.14%)	0.67
Stroke	2699 (8.78%)	2194 (8.86%)	505 (8.45%)	0.32
Ileus	1255 (4.09%)	961 (3.88%)	295 (4.93%)	<0.001
Wound Complications	564 (1.84%)	463 (1.87%)	101 (1.69%)	0.34
Sepsis	1304 (4.24%)	992 (4.01%)	311 (5.21%)	<0.001
Hemorrhage	13,792 (44.89%)	11,197 (45.23%)	2595 (43.47%)	0.01

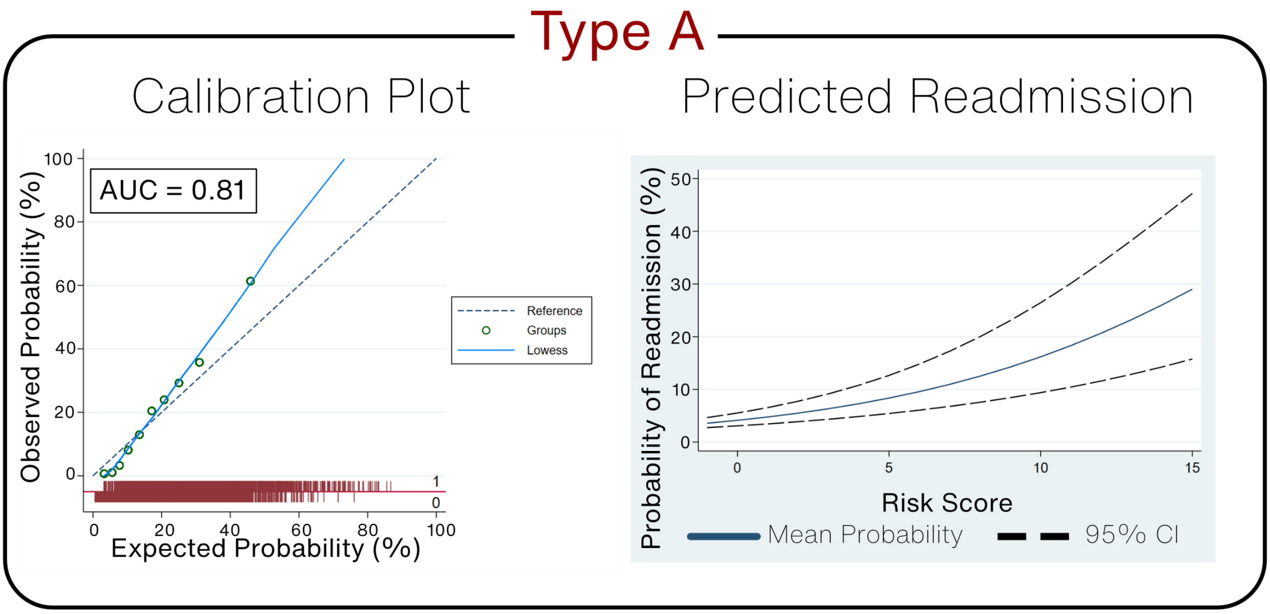

Fig. 1. Calibration plot and predicted readmission plot to validate the predictive model for 30-day readmission after acute type A aortic dissection (ATAAD).

is usually acute in nature, it is likely to have been addressed during the index admission—hence the negative association. Based on the Johnson criteria, which attributes risk scores to variables based on their associated odds ratio, the highest risk score of six points was attributed to resident status. It is worth noting that the data element 'Resident' in the NRD identifies a patient as a resident of a State in which he or she received care. While this does not capture all readmissions, as NRD does not track readmissions across States [12], it does reflect a majority of readmissions and non-readmissions since most patients are readmitted to the hospitals where initial treatment was sought [13,14]. In our case, close to 90% of patients were State residents, irrespective of readmission status. It thus seems conceivable that a resident patient, with other risk factors for readmission too, would have a higher probability of being readmitted—to the same institution in the index State—compared with non-residents who may either be readmitted out of State or may not be readmitted. Thus, being a resident of the State where initial care was sought could be a contributing geographical factor for readmission and not necessarily a systems issue. Further clarification of this data element can only be gleaned if readmission data across State lines are provided in the NRD. Other factors that contributed to readmissions included hypertension, CKD, MI, and transfer to a Skilled Nursing Facility (SNF) or an Intermediate Care Fa-

Table 3. Type A bootstrapped mixed effects regression model.

Variable	OR	CI	*p*-value	Risk points
Weekend Admission	1.09	[0.97, 1.24]	0.15	0
Resident of Hospital State	2.01	[1.64, 2.47]	<0.001	6
Baseline Factors				
Coagulation Disorders	1.12	[0.97, 1.28]	0.112	0
Other Cardiac Conditions*	1.00	[0.87, 1.14]	0.969	0
Hypertension	1.18	[1.01, 1.37]	0.035	1
Coronary Artery Disease	1.07	[0.94, 1.22]	0.3	0
Congestive Heart Failure	1.07	[0.91, 1.26]	0.432	0
Chronic Kidney Disease	1.35	[1.16, 1.56]	0	2
Hospital Complications				
Myocardial Infarction	1.20	[1.00, 1.45]	0.048	2
Pneumonia	0.98	[0.83, 1.15]	0.77	0
Acute Kidney Injury	1.00	[0.86, 1.15]	0.951	0
Spinal Cord Ischemia	1.13	[0.72, 1.77]	0.595	0
Ileus	1.20	[0.91, 1.59]	0.197	0
Sepsis	1.09	[0.81, 1.48]	0.566	0
Bleeding	0.86	[0.76, 0.98]	0.026	–1
Disposition (Ref Routine)				
Transfer to Short Term	0.97	[0.64, 1.47]	0.873	0
Transfer to Other (SNF, ICF)	1.31	[1.09, 1.57]	0.003	2
Home Health Care	1.06	[0.91, 1.24]	0.452	0

*Valvular disease is not included in this variable.

SNF, Skilled Nursing Facility; ICF, Intermediate Care Facility.

cility (ICF), all of which were attributed a risk score of two. The association of these factors with readmission is not entirely novel as they have been previously associated with readmission. For example, it is known that patients discharged home from SNF are more prone to adverse events compared to those discharged home from the hospital [15]. This relationship was reflected in our analyses as well with discharge to SNF being associated with readmission after ATAAD. The association of transfer to SNF or ICF with 30-day readmission could also be a consequence of early discharge to reduce hospital stays despite patients not being fit enough for it. Further, in an NRD study on coronary artery bypass graft (CABG) patients, CKD was strongly associated with risk of readmission [16]. This relationship is also reflected in the ATAAD population in this study. Additionally, there are reports of hypertension being associated with readmission in the heart failure population [17]. As hypertension directly impacts the vasculature, it is plausible to assume that it could lead to adverse outcomes in ATAAD patients with an already weakened aorta.

The results demonstrate good internal validation of the regression model as evidenced by the AUC of 0.81 and the mapping of risk points to the probability of readmission. This indicates that the current method of attributing risk points to different variables based on output of the regression model is good at predicting 30-day readmission in ATAAD patients. The clinical utility of this model at present lies in profiling patients at high risk for readmission following ATAAD treatment. Based on the current model, these would be in-state patients with a high comorbidity burden especially comprising CKD, history of MI, hypertension, and those not being discharged home. Therefore, the management goal for such patients would be to minimize the impact of comorbidities and optimize for home discharge. Further external validation of this model will endorse its clinical utility.

The above results can be interpreted in the context of the Hospital Readmission Reduction Plan (HRRP) initiated by the center for Medicare services with the intention to reduce 30-day readmission and streamline transition of care following discharge [18]. Since readmissions were considered modifiable surrogates of quality of care, hospitals began to be penalized for increased rates of readjusted 30-day readmissions. Originally, MI, pneumonia, and heart failure were included in this program; however, it now comprises CABG, elective total hip (THA) and knee (TKA) arthroplasty, and chronic obstructive pulmonary disease (COPD). While 30-day readmission rates have declined after implementation of this program, questions remain about whether the reduction in readmission is due to higher quality of inpatient care delivery or whether patients receive care in the emergency department and in "observation" units [19]. Adding to the ambiguity is the multi-factorial nature of readmission comprising factors that can not all be managed by a healthcare institution. Several geographic-specific socioeconomic factors such as poverty, housing, access to quality nutrition, social support networks, *etc*., may also impact rates of readmission [18,20].

Increased rates of readmission lead to increase healthcare expenditure [21], and prolonged admissions do not serve any healthcare stakeholder including the patient; however, there is a need to acknowledge the fine distinction between incentivizing discharge and de-incentivizing patient care for fear of financial penalties. Additionally, safety net hospitals, where a great number of patients of low socioeconomic status seek care, may be disproportionately penalized solely on readmission rates [18,20]. As such, there is a need to further refine how the HRRP is implemented before additional target conditions are included in it. Nevertheless, our analysis provides new insight into 30-day readmissions data for patients with ATAAD. Factors associated with readmission may be opportunities for intervention to improve outcomes for ATAAD.

Limitations

The primary limitation of this study is related to its retrospective nature and the potential for selection bias. Further, use of an administrative database prevents granular patient-level analysis. Longer readmission metrics such as 90-day and one-year readmission rates also need to be incorporated for future analysis as some diseases have late-onset complications. Nevertheless, 30-day readmission is a useful metric for assessing early outcomes of diseases.

The NRD does not include patients who may be readmitted out of the State where they initially obtained treatment. As such, not all readmissions could be accounted for. Further, use of ICD9 and ICD10 billing codes for patient identification may also have led to exclusion of some patients. The findings of this study should be taken in context of these limitations.

Conclusions

This novel readmission risk model showed that being a resident of a State where initial care was sought was the most impactful predictor of 30-day readmission after ATAAD. Other comorbidities and socio-economic factors also influence readmission rates. The model showed good calibration and assessing it on different populations is needed for further validation. Variables associated with readmission can be considered as areas for active intervention to reduce readmission rates post-ATAAD.

Abbreviations

ATAAD, Acute type A aortic dissection; ICD, International Classification of Diseases; HRRP, Hospital Readmissions Reduction Program; NRD, Nationwide Readmissions Database; AKI, Acute Kidney Injury; MI, Myocardial Infarction; CKD, Chronic Kidney Disease; HHC, Home Health Care.

Availability of Data and Materials

Available upon reasonable request.

Author Contributions

EAM, IS, SY, JAB, DA, DSG, GJA, RR, JP conceived the study while EAM, IS, SY, JAB, DA designed the research study. EAM and YW analyzed the data. EAM, YW, IS, SY, JAB, DA, DSG, GJA, RR, JP interpreted the data. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

Not applicable.

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Conflict of Interest

The authors declare no conflict of interest. IS receives institutional research support from Abbott, Atricure, Artivion, Boston Scientific, Edwards, Medtronic, Terumo Aortic. These conflicts are unrelated to this article.

Supplementary Material

Supplementary material associated with this article can be found, in the online version, at https://doi.org/10.59958/hsf.6819.

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