

Evaluation of Risk-Adjusted 30-day Home-Time after Transcatheter Aortic Valve Replacement as a Hospital-level Quality Metric

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Supplemental Table 1: Candidate variables considered and tested for each risk adjustment model for the outcomes of 30-day home time, 30-day mortality and 30-day readmission. These variables included patient age, sex, race, chronic conditions (CC) defined by mapping international classification of diseases (ICD) codes 9 and 10 using published CMS risk models ¹, or ICD codes for conditions deemed important by clinical expertise or prior literature.

Condition	Definition
Tuberculosis	cc1
Septicemia	cc2
Bacterial infection; unspecified site	cc3
Mycoses	cc4
HIV infection	cc5
Hepatitis	cc6
Viral infection	cc7
Other infections; including parasitic	cc8
Sexually transmitted infections	cc9
Immunizations and screening for infectious disease	cc10
Cancer of head and neck	cc11
Cancer of esophagus	cc12
Cancer of stomach	cc13
Cancer of colon	cc14
Cancer of rectum and anus	cc15
Cancer of liver and intrahepatic bile duct	cc16
Cancer of pancreas	cc17
Cancer of other GI organs; peritoneum	cc18
Cancer of bronchus; lung	cc19
Cancer; other respiratory and intrathoracic	cc20
Cancer of bone and connective tissue	cc21
Melanomas of skin	cc22
Other non-epithelial cancer of skin	cc23
Cancer of breast	cc24
Cancer of uterus	cc25
Cancer of cervix	cc26
Cancer of ovary	cc27
Cancer of other female genital organs	cc28
Cancer of prostate	cc29
Cancer of testis	cc30
Cancer of other male genital organs	cc31
Cancer of bladder	cc32
Cancer of kidney and renal pelvis	cc33
Cancer of other urinary organs	cc34
Cancer of brain and nervous system	cc35
Cancer of thyroid	cc36
Hodgkin`s disease	cc37
Non-Hodgkin`s lymphoma	cc38
Leukemia	cc39
Multiple myeloma	cc40
Cancer; other and unspecified primary	cc41
Secondary malignancies	cc42
Malignant neoplasm without specification of site	cc43

Neoplasms of unspecified nature or uncertain behavior	cc44
Maintenance chemotherapy; radiotherapy	cc45
Benign neoplasm of uterus	cc46
Other and unspecified benign neoplasm	cc47
Thyroid disorders	cc48
Diabetes mellitus without complication	cc49
Diabetes mellitus with complications	cc50
Other endocrine disorders	cc51
Nutritional deficiencies	cc52
Disorders of lipid metabolism	cc53
Gout and other crystal arthropathies	cc54
Fluid and electrolyte disorders	cc55
Cystic fibrosis	cc56
Immunity disorders	cc57
Other nutritional; endocrine; and metabolic disorders	cc58
Deficiency and other anemia	cc59
Acute post-hemorrhagic anemia	cc60
Sickle cell anemia	cc61
Coagulation and hemorrhagic disorders	cc62
Diseases of white blood cells	cc63
Other hematologic conditions	cc64
Meningitis (except that caused by tuberculosis or sexually transmitted disease)	cc76
Encephalitis (except that caused by tuberculosis or sexually transmitted disease)	cc77
Other CNS infection and poliomyelitis	cc78
Parkinson`s disease	cc79
Multiple sclerosis	cc80
Other hereditary and degenerative nervous system conditions	cc81
Paralysis	cc82
Epilepsy; convulsions	cc83
Headache; including migraine	cc84
Coma; stupor; and brain damage	cc85
Cataract	cc86
Retinal detachments; defects; vascular occlusion; and retinopathy	cc87
Glaucoma	cc88
Blindness and vision defects	cc89
Inflammation; infection of eye (except that caused by tuberculosis or sexually transmitted disease)	cc90
Other eye disorders	cc91
Otitis media and related conditions	cc92
Conditions associated with dizziness or vertigo	cc93
Other ear and sense organ disorders	cc94
Other nervous system disorders	cc95
Heart valve disorders	cc96
Peri-; endo-; and myocarditis; cardiomyopathy	cc97
Essential hypertension	cc98
Hypertension with complications and secondary hypertension	cc99
Acute myocardial infarction	cc100

Coronary atherosclerosis and other heart disease	cc101
Nonspecific chest pain	cc102
Pulmonary heart disease	cc103
Other and ill-defined heart disease	cc104
Conduction disorders	cc105
Cardiac dysrhythmias	cc106
Cardiac arrest and ventricular fibrillation	cc107
Congestive heart failure; non-hypertensive	cc108
Acute cerebrovascular disease	cc109
Occlusion or stenosis of pre-cerebral arteries	cc110
Other and ill-defined cerebrovascular disease	cc111
Transient cerebral ischemia	cc112
Late effects of cerebrovascular disease	cc113
Peripheral and visceral atherosclerosis	cc114
Aortic; peripheral; and visceral artery aneurysms	cc115
Aortic and peripheral arterial embolism or thrombosis	cc116
Other circulatory disease	cc117
Phlebitis; thrombophlebitis and thromboembolism	cc118
Varicose veins of lower extremity	cc119
Hemorrhoids	cc120
Other diseases of veins and lymphatics	cc121
Pneumonia (except that caused by tuberculosis or sexually transmitted disease)	cc122
Influenza	cc123
Acute and chronic tonsillitis	cc124
Acute bronchitis	cc125
Other upper respiratory infections	cc126
Chronic obstructive pulmonary disease and bronchiectasis	cc127
Asthma	cc128
Aspiration pneumonitis; food/vomitus	cc129
Pleurisy; pneumothorax; pulmonary collapse	cc130
Respiratory failure; insufficiency; arrest (adult)	cc131
Lung disease due to external agents	cc132
Other lower respiratory disease	cc133
Other upper respiratory disease	cc134
Intestinal infection	cc135
Disorders of teeth and jaw	cc136
Diseases of mouth; excluding dental	cc137
Esophageal disorders	cc138
Gastroduodenal ulcer (except hemorrhage)	cc139
Gastritis and duodenitis	cc140
Other disorders of stomach and duodenum	cc141
Appendicitis and other appendiceal conditions	cc142
Abdominal hernia	cc143
Regional enteritis and ulcerative colitis	cc144
Intestinal obstruction without hernia	cc145
Diverticulosis and diverticulitis	cc146
Anal and rectal conditions	cc147
Peritonitis and intestinal abscess	cc148

Biliary tract disease	cc149
Liver disease; alcohol-related	cc150
Other liver diseases	cc151
Pancreatic disorders (not diabetes)	cc152
Gastrointestinal hemorrhage	cc153
Noninfectious gastroenteritis	cc154
Other gastrointestinal disorders	cc155
Nephritis; nephrosis; renal sclerosis	cc156
Acute and unspecified renal failure	cc157
Chronic kidney disease	cc158
Urinary tract infections	cc159
Calculus of urinary tract	cc160
Other diseases of kidney and ureters	cc161
Other diseases of bladder and urethra	cc162
Genitourinary symptoms and ill-defined conditions	cc163
Hyperplasia of prostate	cc164
Inflammatory conditions of male genital organs	cc165
Other male genital disorders	cc166
Nonmalignant breast conditions	cc167
Inflammatory diseases of female pelvic organs	cc168
Endometriosis	cc169
Prolapse of female genital organs	cc170
Menstrual disorders	cc171
Ovarian cyst	cc172
Menopausal disorders	cc173
Skin and subcutaneous tissue infections	cc197
Other inflammatory condition of skin	cc198
Chronic ulcer of skin	cc199
Other skin disorders	cc200
Infective arthritis and osteomyelitis	cc201
Rheumatoid arthritis and related disease	cc202
Osteoarthritis	cc203
Other non-traumatic joint disorders	cc204
Spondylosis; intervertebral disc disorders; other back problems	cc205
Osteoporosis	cc206
Pathological fracture	cc207
Acquired foot deformities	cc208
Other acquired deformities	cc209
Systemic lupus erythematosus and connective tissue disorders	cc210
Other connective tissue disease	cc211
Other bone disease and musculoskeletal deformities	cc212
Cardiac and circulatory congenital anomalies	cc213
Digestive congenital anomalies	cc214
Genitourinary congenital anomalies	cc215
Nervous system congenital anomalies	cc216
Other congenital anomalies	cc217
Joint disorders and dislocations; trauma-related	cc225
Fracture of neck of femur (hip)	cc226
Spinal cord injury	cc227

Skull and face fractures	cc228
Fracture of upper limb	cc229
Fracture of lower limb	cc230
Other fractures	cc231
Sprains and strains	cc232
Intracranial injury	cc233
Crushing injury or internal injury	cc234
Open wounds of head; neck; and trunk	cc235
Open wounds of extremities	cc236
Superficial injury; contusion	cc239
Burns	cc240
Poisoning by psychotropic agents	cc241
Poisoning by other medications and drugs	cc242
Poisoning by nonmedicinal substances	cc243
Other injuries and conditions due to external causes	cc244
Syncope	cc245
Fever of unknown origin	cc246
Lymphadenitis	cc247
Gangrene	cc248
Shock	cc249
Nausea and vomiting	cc250
Abdominal pain	cc251
Malaise and fatigue	cc252
Allergic reactions	cc253
Prior pacemaker	V4501, Z950, Z4501, 0JH606Z, 02H63JZ, 02HK3JZ, 3783, 3772
Prior intra-cardiac defibrillator	0JH608Z, 02H63KZ, 02HK3KZ, 3794, V4502, Z95810, Z4502
Prior percutaneous coronary intervention	0066, 1755, 3601, 3602, 3603, 3605, 3603, 3607, 3609, 0250047, 027004Z, 02700D6, 02700DZ, 02700T6, 02500TZ, 02700Z6, 02700ZZ, 0270346, 027034Z, 02703D6, 02703DZ, 02703T6, 02703TZ, 02703Z6, 02703TZ, 02703Z6, 02703ZZ, 0270446, 027044Z, 02704D6, 02704DZ, 02407TZ, 02404Z6, 02404ZZ, 0271046, 027104Z, 02710D6, 02710DZ, 02710T6, 02710Z6, 02710ZZ, 0271346, 027134Z, 02713D6, 02713DZ, 02713T6, 02713TZ, 02713Z6, 02713ZZ, 0271446, 027144Z, 02714D6, 02714DZ, 02714T6, 02714TZ, 02714Z6, 02714ZZ, 0272046, 027204Z, 02720D6, 02020DZ, 02720T6, 02720TZ, 02720Z6, 02720ZZ, 0272346, 027234Z, 72723D6', 02723DZ, 02723T6,

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Prior coronary artery bypass grafting surgery	02100*, 02110*, 02120*, 02130*, 3611, 3612, 3613, 3614 , 3615, 3616
Decubitus ulcer	L89*, 70700, 70701, 70702, 70703, 70704, 70705, 70706, 70707, 70709 , 70720, 70721, 70722, 70723, 70724, 70725
Delirium	F05*, 2930, 2931
Dysphagia	R13*, 78720, 78721, 78722, 78723, 78724, 78729
Hypotension	I95*, 4580, 4581, 45821, 45829, 4588, 4589
Urinary incontinence	R32*, 78830
Urinary retention	R33*, 78820, 78829
Alzheimer's disease	G81* , 34200, 34201, 34202, 34210, 34211, 34212, 34280, 34281, 34282, 34290, 34291, 34292
Falls	W19*, W06*, W10*, W01*, W18*, E8889, E9293, E8844, E9293, E8800, E8801, E8809, E9293, E8859, E8880, E8881, E9293, E8846, E8859, E8880, E8881, E8888, E9178, E9293
Abnormal gait	R26*, 7197, 7812
Pneumonitis due to solid and liquids	J69*, 5070, 5071, 5078
Unspecified Dementia	F03*, 2900, 29010, 29011, 29013, 29021, 2908, 2909, 29420, 29421
Vascular dementia	F01*, 29040, 29041

1: <https://www.cms.gov/Medicare/Health-Plans/MedicareAdvtgSpecRateStats/Risk-Adjustors.html>

Supplemental Table 2: Final variables included in the risk adjustment model for 30-day home time in the whole study cohort. These are variables that were significant at a level of $P < 0.01$ in at least 80% of the 100 models done on bootstrapped samples in the training/derivation data set. Models were performed as generalized linear mixed models with a random intercept for the TAVR hospital. All chronic conditions (CC) are defined by mapping international classification of diseases (ICD) codes 9 and 10 to each chronic condition using published CMS risk models.¹

Definition used to define the variable	Variable	Parameter Estimate	Standard error	P value
	Age	-0.0048	7.1E-05	<0.001
	Male sex	0.03848	0.00108	<0.001
cc103	Pulmonary heart disease	-0.0092	0.00117	<0.001
cc104	Other and ill-defined heart disease	-0.0248	0.00306	<0.001
cc105	Conduction disorders	-0.0208	0.00101	<0.001
cc106	Cardiac dysrhythmias	-0.033	0.00099	<0.001
cc107	Cardiac arrest and ventricular fibrillation	-0.3293	0.00429	<0.001
cc108	Congestive heart failure; non-hypertensive	-0.0183	0.00121	<0.001
cc109	Acute cerebrovascular disease	-0.2833	0.00303	<0.001
cc114	Peripheral and visceral atherosclerosis	-0.023	0.00119	<0.001
cc115	Aortic; peripheral; and visceral artery aneurysms	-0.0487	0.00182	<0.001
cc116	Aortic and peripheral arterial embolism or thrombosis	-0.1576	0.00507	<0.001
cc117	Other circulatory disease	0.00757	0.00122	<0.001
cc118	Phlebitis; thrombophlebitis and thromboembolism	-0.0233	0.00198	<0.001
cc121	Other diseases of veins and lymphatics	-0.0182	0.00267	<0.001
cc122	Pneumonia (except that caused by tuberculosis or sexually transmitted disease)	-0.0153	0.00197	<0.001
cc127	Chronic obstructive pulmonary disease and bronchiectasis	-0.0122	0.00115	<0.001
cc129	Aspiration pneumonitis; food/vomitus	-0.122	0.00474	<0.001
cc130	Pleurisy; pneumothorax; pulmonary collapse	-0.1058	0.00182	<0.001
cc131	Respiratory failure; insufficiency; arrest (adult)	-0.0727	0.0015	<0.001
cc135	Intestinal infection	-0.0558	0.00529	<0.001
cc139	Gastroduodenal ulcer (except hemorrhage)	0.02024	0.00273	<0.001
cc145	Intestinal obstruction without hernia	-0.0555	0.00454	<0.001
cc146	Diverticulosis and diverticulitis	0.0298	0.00226	<0.001
cc151	Other liver diseases	-0.0186	0.00214	<0.001
cc153	Gastrointestinal hemorrhage	-0.0182	0.00255	<0.001
cc155	Other gastrointestinal disorders	-0.0302	0.0015	<0.001
cc156	Nephritis; nephrosis; renal sclerosis	-0.0582	0.00481	<0.001
cc157	Acute and unspecified renal failure	-0.1016	0.00151	<0.001
cc158	Chronic kidney disease	-0.0087	0.00109	<0.001
cc159	Urinary tract infections	-0.0601	0.00177	<0.001
cc160	Calculus of urinary tract	0.03062	0.00294	<0.001
cc163	Genitourinary symptoms and ill-defined conditions	-0.0217	0.00192	<0.001

cc164	Hyperplasia of prostate	0.01314	0.00143	<0.001
cc165	Inflammatory conditions of male genital organs	0.06011	0.01102	<0.001
cc173	Menopausal disorders	0.05863	0.00416	<0.001
cc197	Skin and subcutaneous tissue infections	-0.0435	0.00325	<0.001
cc199	Chronic ulcer of skin	-0.0747	0.00341	<0.001
cc201	Infective arthritis and osteomyelitis	0.07004	0.00702	<0.001
cc204	Other non-traumatic joint disorders	-0.0441	0.00265	<0.001
cc209	Other acquired deformities	-0.0279	0.00393	<0.001
cc23	Other non-epithelial cancer of skin	0.01958	0.00197	<0.001
cc233	Intracranial injury	0.03494	0.00579	<0.001
cc234	Crushing injury or internal injury	-0.0985	0.00658	<0.001
cc239	Superficial injury; contusion	-0.024	0.00356	<0.001
cc244	Other injuries and conditions due to external causes	-0.0475	0.00225	<0.001
cc248	Gangrene	-0.0814	0.01319	<0.001
cc249	Shock	-0.23	0.00305	<0.001
cc253	Allergic reactions	0.02253	0.0012	<0.001
ICD codes	Prior ICD	0.05637	0.00384	<0.001
ICD codes	Prior pacemaker	0.06475	0.0021	<0.001
ICD codes	Dementia	-0.0476	0.00227	<0.001
ICD codes	Delirium	-0.0516	0.00134	<0.001
ICD codes	Abnormal gait	-0.0141	0.0009	<0.001
ICD codes	Dysphagia	-0.0979	0.00408	<0.001
ICD codes	Hypotension	-0.0298	0.00106	<0.001
ICD codes	Prior PCI	0.01612	0.00107	<0.001
ICD codes	Urinary retention	-0.0225	0.00202	<0.001
ICD codes	Volume depletion	0.01751	0.00094	<0.001

1: <https://www.cms.gov/Medicare/Health-Plans/MedicareAdvtgSpecRateStats/Risk-Adjustors.html>

Supplemental Table 3: Final variables included in the risk adjustment model for 30-day mortality in the whole study cohort. These are variables that were significant at a level of $P < 0.01$ in at least 80% of the 100 models done on bootstrapped samples in the training/derivation data set. Models were performed as mixed effect hierarchical logistic regression with a random intercept for the TAVR hospital. All chronic conditions (CC) are defined by mapping international classification of diseases (ICD) codes 9 and 10 to each chronic condition using published CMS risk models.¹

Definition used to define the variable	Parameter	Estimate	Standard error	P value
	Age	0.04693	0.00244	<0.001
cc10	Immunizations and screening for infectious disease	-0.2736	0.07641	<0.001
cc105	Conduction disorders	-0.2603	0.03328	<0.001
cc106	Cardiac dysrhythmias	0.1716	0.03604	<0.001
cc107	Cardiac arrest and ventricular fibrillation	1.9853	0.04837	<0.001
cc109	Acute cerebrovascular disease	0.9818	0.05621	<0.001
cc113	Late effects of cerebrovascular disease	-0.438	0.08854	<0.001
cc114	Peripheral and visceral atherosclerosis	0.1928	0.03587	<0.001
cc115	Aortic; peripheral; and visceral artery aneurysms	0.5108	0.04636	<0.001
cc116	Aortic and peripheral arterial embolism or thrombosis	0.5351	0.09271	<0.001
cc130	Pleurisy; pneumothorax; pulmonary collapse	0.2629	0.04097	<0.001
cc131	Respiratory failure; insufficiency; arrest (adult)	0.7582	0.03673	<0.001
cc151	Other liver diseases	0.4011	0.04912	<0.001
cc157	Acute and unspecified renal failure	0.6106	0.03654	<0.001
cc249	Shock	1.2915	0.04302	<0.001
ICD codes	Hypotension	0.1876	0.02388	<0.001

1: <https://www.cms.gov/Medicare/Health-Plans/MedicareAdvtgSpecRateStats/Risk-Adjustors.html>

Supplemental Table 4: Final variables included in the risk adjustment model for 30-day readmission in the whole study cohort. These are variables that were significant at a level of $P < 0.01$ in at least 80% of the 100 models done on bootstrapped samples in the training/derivation data set. Models were performed as mixed effect hierarchical logistic regression with a random intercept for the TAVR hospital. All chronic conditions (CC) are defined by mapping international classification of diseases (ICD) codes 9 and 10 to each chronic condition using published CMS risk models.¹

Definition used to define the variable	Parameter	Parameter Estimate	Standard error	P value
	Age	0.01823	0.00104	<.0001
	Male sex	-0.0699	0.01417	<.0001
cc102	Nonspecific chest pain	0.1504	0.0372	<.0001
cc103	Pulmonary heart disease	0.09747	0.01552	<.0001
cc106	Cardiac dysrhythmias	0.2532	0.01449	<.0001
cc108	Congestive heart failure	0.1374	0.01855	<.0001
cc109	Acute cerebrovascular disease	0.6482	0.0293	<.0001
cc114	Peripheral and visceral atherosclerosis	0.123	0.01585	<.0001
cc115	Aortic; peripheral; and visceral artery aneurysms	0.1506	0.02328	<.0001
cc116	Aortic and peripheral arterial embolism or thrombosis	0.3515	0.05307	<.0001
cc118	Phlebitis; thrombophlebitis and thromboembolism	0.1053	0.02465	<.0001
cc127	Chronic obstructive pulmonary disease and bronchiectasis	0.1946	0.01542	<.0001
cc130	Pleurisy; pneumothorax; pulmonary collapse	0.2493	0.02037	<.0001
cc131	Respiratory failure; insufficiency; arrest (adult)	0.2218	0.0176	<.0001
cc153	Gastrointestinal hemorrhage	0.1908	0.02772	<.0001
cc155	Other gastrointestinal disorders	0.1611	0.0171	<.0001
cc157	Acute and unspecified renal failure	0.342	0.01774	<.0001
cc158	Chronic kidney disease	0.1457	0.01542	<.0001
cc159	Urinary tract infections	0.144	0.02012	<.0001
cc199	Chronic ulcer of skin	0.207	0.03341	<.0001
ICD codes	Delirium	0.09228	0.01349	<.0001
ICD codes	Prior Pacemaker	-0.1001	0.02582	0.0001
ICD codes	Sleep apnea	0.1213	0.01788	<.0001
ICD codes	Urinary Retention	0.1741	0.01849	<.0001

1: <https://www.cms.gov/Medicare/Health-Plans/MedicareAdvtgSpecRateStats/Risk-Adjustors.html>

Supplemental Table 5: Performance of the risk adjustment models for different hospital-level performance metrics for Transcatheter aortic valve replacement hospitalization in the development and validation cohort

	Parameter	Derivation cohort	Validation cohort
30-day home time	R ²	0.216	0.214
30-day mortality	C-statistics	0.82	0.82
30-day readmission	C-statistics	0.66	0.65

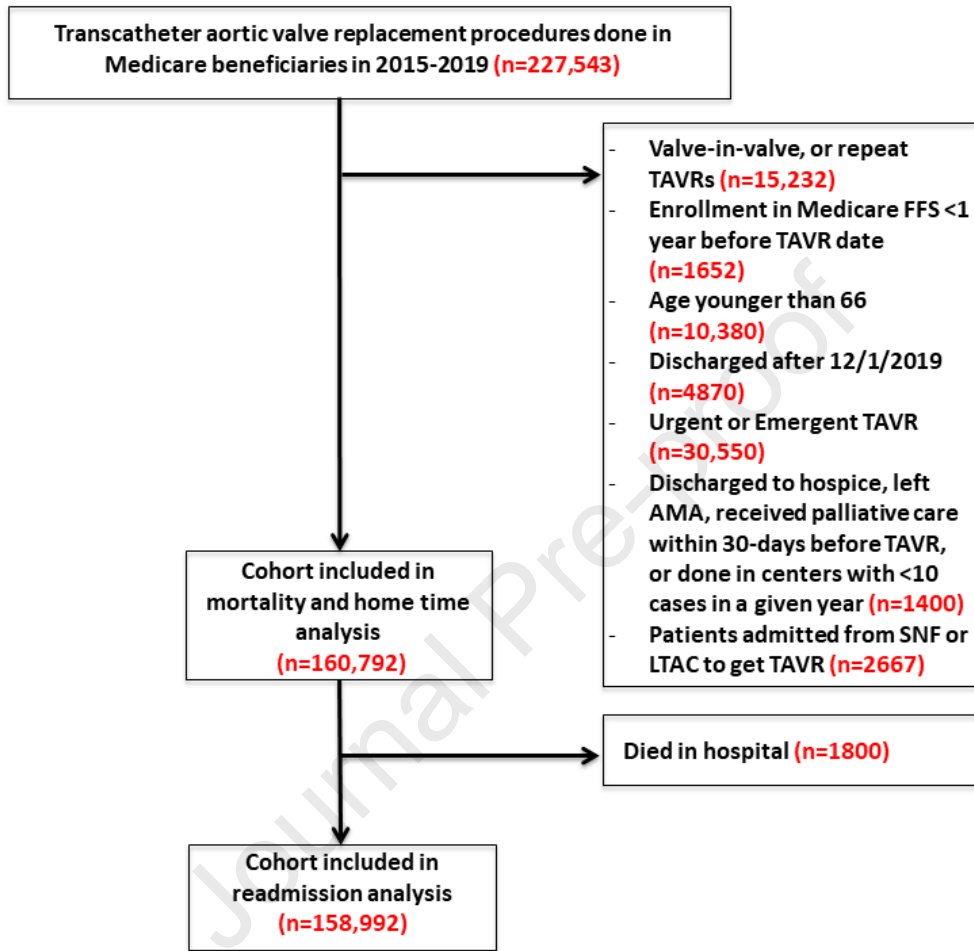
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Supplemental Table 6: Hospital-level outcomes across hospital groups stratified unadjusted 30-day home time among patients undergoing TAVR

Variable	Low Performing → High Performing				P Value
	Quartile 1 (N=163)	Quartile 2 (N=163)	Quartile 3 (N=163)	Quartile 4 (N=163)	
Length of hospital stay day after TAVR procedure Median (IQR), days	2.60 (2.3-3.0)	2.16 (1.9-2.4)	1.83 (1.7-2.0)	1.50 (1.3-1.7)	<0.001
30-day home time Median (IQR), days	24.2 (23.4-24.6)	25.5 (25.2-25.7)	26.4 (26.2-26.7)	27.6 (27.0-28.1)	<0.001
30-RSRR Median (IQR) (%)	14.8 (11.4-20.1)	13.6 (10.6-17.7)	12.8 (9.2-15.8)	9.3 (6.8-12.4)	<0.001
30-RSMR Median (IQR) (%)	2.6 (1.6-4.0)	2.1 (1.1-3.1)	1.7 (1.0-2.7)	0.7 (0.0-1.7)	<0.001
Annual TAVR Volume median (IQR)	57 (35-102)	66 (38-98)	65 (42-107)	38 (24-62)	0.05

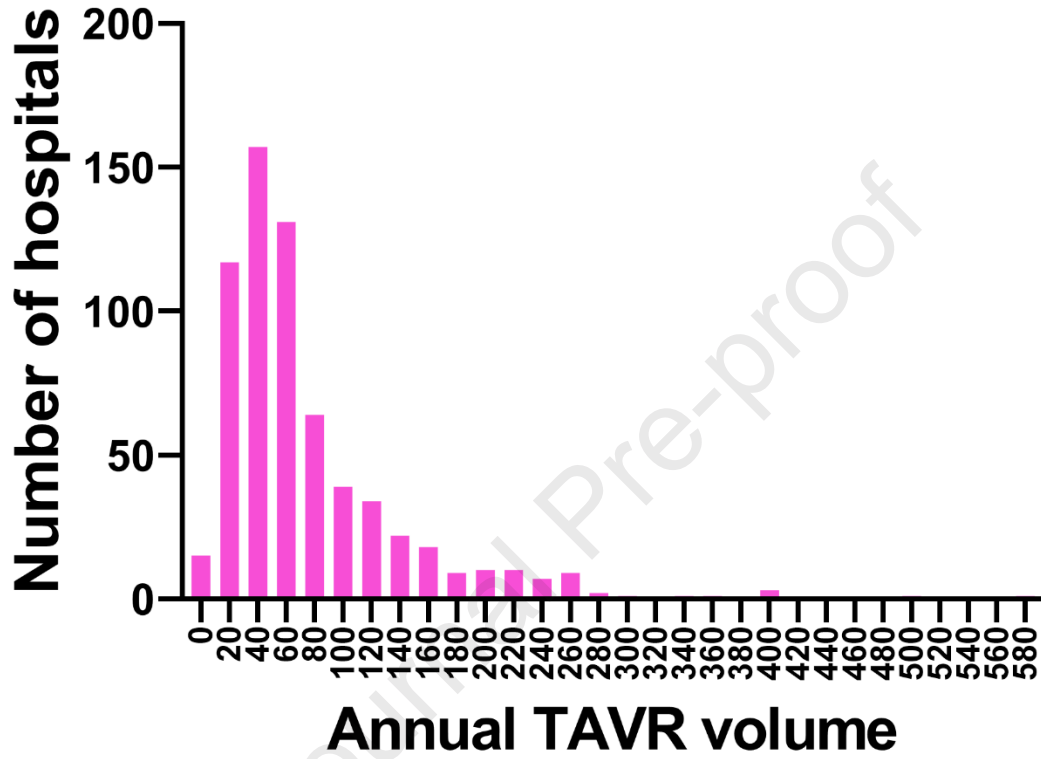
IQR: Inter quartile range; TAVR: Transcatheter aortic valve replacement; RSRR: Risk-adjusted readmission rate; RSMR: Risk-adjusted mortality rate

Supplemental Figure 1: Flow chart of the study cohort selection.

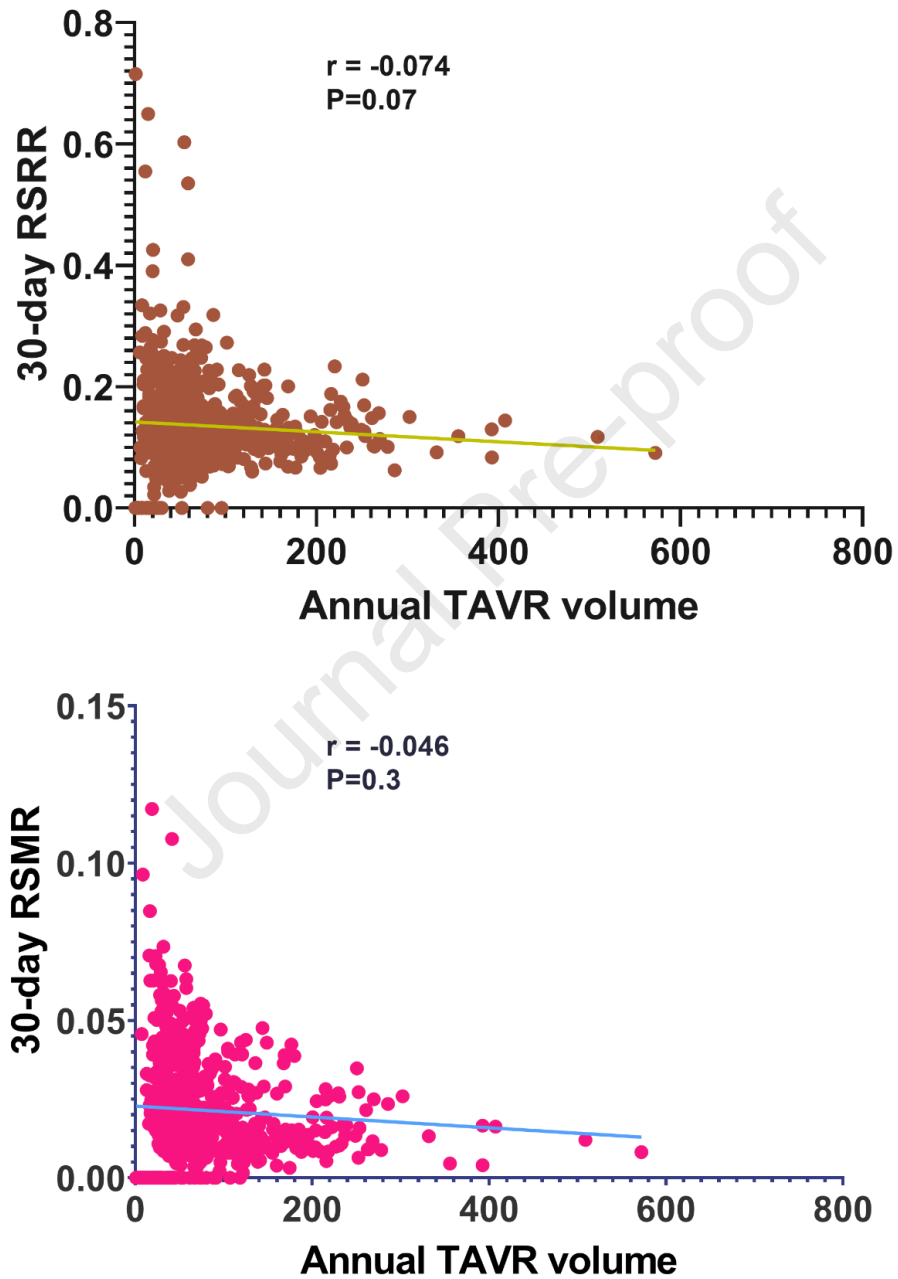


Supplemental Figure 2: Histogram of TAVR annual volume: Frequency distribution of average annual TAVR procedure volume for TAVR centers included in the study

Distribution of annual hospital TAVR volume



Supplemental Figure 3: Correlation between hospital TAVR volume and other hospital quality metrics. Correlation between TAVR center annual volume and a) 30-day RSMR, b) 30-day RSRR



Supplemental Figure 4: Correlation between 30-day home time and admissions over one year. Correlation between hospital risk adjusted 30-day home time and rate of admissions per patient-month time for 1 year. Cohort of patients who were discharged from TAVR hospitalization before 1/1/2019 (N=113,978 patients in 599 centers)

