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Multivariate Logistic Regression Modeling and Construction of the VTE Risk Index

Primary Model

A single multivariate logistic regression model for the outcome of postoperative VTE was constructed using a random 90% of the sample. Covariate terms included age, sex, race/ethnicity (white, black, Hispanic, or other), comorbidities (congestive heart failure, diabetes, neurologic disease, cancer, primary hypercoagulability, secondary hypercoagulability, obesity, hypertension, renal failure), procedural characteristics (anterior cervical fusion, posterior cervical fusion, anterior thoracic fusion, posterior thoracic fusion, anterior lumbar fusion, posterior lumbar fusion, combined anterior-posterior approach, four or more levels fused, revision surgery), and primary diagnosis (degenerative disc disease, spinal stenosis, spinal deformity, spondylolisthesis, or trauma). Interaction terms were calculated between age and procedural characteristics, age and primary diagnosis, sex and procedural characteristics, and sex and primary diagnosis.

Creation of the VTE Risk Index from the output of the logistic regression model was based on the methodology used by Sullivan et al. for calculation of the Framingham Risk Score[24]. Consistent with the methodology used by Sullivan et al., regression units were converted into points by dividing each regression coefficient by 0.15 (roughly equivalent to the increased risk of VTE following a seven-year increase in age) and rounding to the nearest integer. A patient's final risk score was calculated by adding up the points for each risk factor. The model was estimated from a random 90% sample of the population and was validated in the remaining 10%. A Hosmer-Lemeshow goodness-of-fit test, modified for use with survey weights, was used to analyze the performance of the regression model, and the remaining 10% sample was used to assess the performance of the risk score relative to the regression model predictions[25].

Following the method of Collins et al., the index was validated in the 10% sample that had not been included in the regression analysis by comparing the VTE probability predicted by the regression model with the probability predicted from the risk index[23]. The predicted VTE incidence was 0.501% (95% confidence interval [CI], 0.485% to 0.517%) on the basis of the regression model compared with 0.495% on the basis of the risk index. The risk index therefore closely approximated the prediction provided by the regression model. This comparison, combined with the favorable model fit, validates the proposed VTE Risk Index. The predicted VTE incidence for each total point value in the VTE Risk Index is presented in Table E-2.

Alternate Risk Index with Hypercoagulability Excluded

Because the NIS data are cross-sectional in nature, the possibility exists that a discharge diagnosis of hypercoagulability is secondary to the occurrence of a VTE during the admission rather than to a comorbidity diagnosed prior to admission. For this reason, a separate analysis was performed in which primary and secondary hypercoagulability were excluded from the model. Excluding hypercoagulability had little effect on the predicted VTE probability because hypercoagulability was rare in the observed data (total, <0.2% for both diagnoses). ■

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TABLE E-1 Results of Multivariate Logistic Regression Model for Occurrence of Postoperative VTE*

Variable	OR	95% CI		P Value
Age	1.02	1.02	1.03	<0.0001
Female sex	0.78	0.62	1.00	0.0465
Race/ethnicity, ref. = white				
Black	1.60	1.39	1.84	<0.0001
Hispanic	1.18	0.96	1.45	0.1172
Other	1.06	0.82	1.36	0.6717
Comorbidities				
Congestive heart failure	2.11	1.78	2.51	<0.0001
Diabetes	1.08	0.98	1.20	0.1219
Neurologic disease	1.47	1.25	1.72	<0.0001
Cancer	3.02	2.61	3.51	<0.0001
Primary hypercoagulability	12.19	8.88	16.73	<0.0001
Secondary hypercoagulability	3.63	1.94	6.77	0.0001
Obesity	1.44	1.26	1.66	<0.0001
Hypertension	0.82	0.75	0.89	<0.0001
Renal failure	1.60	1.30	1.96	<0.0001
Approach and surgery				
Anterior cervical	0.39	0.22	0.68	0.0010
Posterior cervical	0.91	0.53	1.56	0.7380
Anterior lumbar	0.64	0.33	1.24	0.1814
Posterior lumbar	0.53	0.33	0.85	0.0082
Anterior thoracic	0.83	0.36	1.90	0.6608
Posterior thoracic	0.69	0.40	1.18	0.1733
Combined anterior-posterior	3.90	1.83	8.30	0.0004
Four or more levels fused	1.93	1.31	2.84	0.0009
Revision surgery	0.21	0.08	0.50	0.0005
Primary diagnosis				
Degenerative disc disease	0.11	0.07	0.19	<0.0001
Spinal stenosis	0.37	0.15	0.92	0.0334
Spondylolisthesis	0.48	0.18	1.29	0.1435
Trauma	6.62	4.47	9.82	<0.0001
Interaction term, age ×:				
Anterior cervical	1.00	0.99	1.01	0.5843
Posterior cervical	1.00	0.99	1.01	0.6324
Anterior lumbar	1.01	1.00	1.02	0.1684
Posterior lumbar	1.00	1.00	1.01	0.2282
Anterior thoracic	1.01	0.99	1.02	0.4728
Posterior thoracic	1.01	1.00	1.02	0.0677
Combined anterior-posterior	0.99	0.98	1.00	0.1009
Four or more levels fused	1.00	0.99	1.00	0.4537
Revision surgery	1.02	1.00	1.03	0.0144
Degenerative disc disease	1.02	1.01	1.03	<0.0001
Spinal stenosis	1.00	0.99	1.02	0.5013
Spondylolisthesis	0.99	0.98	1.01	0.4224
Trauma	0.99	0.98	0.99	0.0002

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TABLE E-1 (*continued*)

Variable	OR	95% CI		P Value
Interaction term, female ×:				
Anterior cervical	0.65	0.49	0.86	0.0026
Posterior cervical	1.26	0.94	1.68	0.1226
Anterior lumbar	1.09	0.77	1.54	0.6293
Posterior lumbar	0.98	0.77	1.25	0.8742
Anterior thoracic	0.98	0.61	1.58	0.9290
Posterior thoracic	1.04	0.74	1.45	0.8387
Combined anterior-posterior	1.11	0.74	1.67	0.6024
Four or more levels fused	1.00	0.84	1.19	0.9747
Revision surgery	0.91	0.60	1.38	0.6521
Degenerative disc disease	1.31	1.08	1.59	0.0054
Spinal stenosis	1.15	0.86	1.52	0.3460
Spondylolisthesis	1.31	0.89	1.92	0.1741
Trauma	0.76	0.60	0.95	0.0188

*All covariates and interaction terms are included.

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TABLE E-2 Postoperative VTE Occurrence According to VTE Risk Index Point Value

Points	VTE Probability *(%)*	N
≤−13	<0.1	86,063
−12	0.12	38,551
−11	0.14	25,550
−10	0.16	47,058
−9	0.19	29,514
−8	0.22	33,722
−7	0.25	47,025
−6	0.29	35,072
−5	0.34	44,723
−4	0.40	25,770
−3	0.46	39,087
−2	0.53	35,847
−1	0.62	18,974
0	0.72	25,646
1	0.84	16,076
2	0.97	14,349
3	1.12	12,529
4	1.30	8937
5	1.51	10,262
6	1.75	6144
7	2.03	7145
8	2.35	7005
9	2.72	4459
10	3.15	3904
11	3.64	3255
12	4.20	2942
13	4.85	1803
14	5.59	1351
15	6.43	912
16	7.40	545
17	8.49	454
18	9.73	262
19	11.13	182
20	12.71	135
21	14.47	80
22	16.42	71
23	18.59	48
≥24	>20	109

TABLE E-3 VTE Diagnosis Codes

	ICD-9-CM Codes
Deep venous thrombosis	451.11, 451.19, 451.2, 451.81, 451.9, 453.40, 453.41, 453.42, 453.9
Pulmonary embolism	415.1, 415.11, 415.19

TABLE E-4 Specific Comorbidities Used in the Analysis*

Congestive heart failure
Diabetes mellitus
Liver disease
Neurologic disease
Cancer
Primary hypercoagulability
Secondary hypercoagulability
Obesity
Hypertension
Renal failure

*See http://www.hcup-us.ahrq.gov/toolssoftware/ccs/ccs.jsp for the corresponding ICD-9-CM codes.

TABLE E-5 Primary Surgical Indications

Indication	ICD-9-CM Diagnosis Codes
Degenerative disc disease	721.0-9, 722.0-9
Spinal stenosis	724.0-09
Scoliosis	737.0-9
Spondylolisthesis	738.4
Traumatic indication	800.0-899.9

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TABLE E-6 Results of Alternate Multivariate Logistic Regression Model*

Variable	OR	95% CI		P Value
Age	1.02	1.02	1.03	<0.01
Female sex	0.79	0.62	1.00	0.05
Race/ethnicity				
Black	1.58	1.38	1.82	<0.01
Hispanic	1.17	0.95	1.44	0.14
Other	1.05	0.82	1.36	0.69
Comorbidities				
Congestive heart failure	2.11	1.77	2.50	<0.01
Diabetes	1.08	0.98	1.20	0.14
Neurologic disease	1.48	1.26	1.73	<0.01
Cancer	3.03	2.61	3.51	<0.01
Obesity	1.46	1.27	1.67	<0.01
Hypertension	0.82	0.75	0.90	<0.01
Renal failure	1.61	1.31	1.97	<0.01
Approach and surgery				
Anterior cervical	0.38	0.22	0.67	<0.01
Posterior cervical	0.90	0.53	1.54	0.70
Anterior lumbar	0.62	0.32	1.20	0.16
Posterior lumbar	0.52	0.32	0.83	0.01
Anterior thoracic	0.82	0.36	1.86	0.63
Posterior thoracic	0.68	0.40	1.17	0.16
Combined anterior-posterior	3.96	1.86	8.41	<0.01
Four or more levels fused	1.92	1.31	2.82	<0.01
Revision surgery	0.20	0.08	0.49	<0.01
Primary diagnosis				
Degenerative disc disease	0.11	0.07	0.19	<0.01
Spinal stenosis	0.37	0.15	0.92	0.03
Spondylolisthesis	0.47	0.17	1.26	0.13
Trauma	6.60	4.46	9.76	<0.01
Interaction term, age ×:				
Anterior cervical	1.00	0.99	1.01	0.53
Posterior cervical	1.00	0.99	1.01	0.67
Anterior lumbar	1.01	1.00	1.02	0.14
Posterior lumbar	1.01	1.00	1.01	0.21
Anterior thoracic	1.01	0.99	1.02	0.46
Posterior thoracic	1.01	1.00	1.02	0.07
Combined anterior-posterior	0.99	0.98	1.00	0.10
Four or more levels fused	1.00	0.99	1.00	0.48
Revision surgery	1.02	1.00	1.03	0.01
Degenerative disc disease	1.02	1.01	1.03	<0.01
Spinal stenosis	1.00	0.99	1.02	0.50
Spondylosis	0.99	0.98	1.01	0.44
Trauma	0.99	0.98	0.99	<0.01

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TABLE E-6 (*continued*)

Variable	OR	95% CI		P Value
Interaction term, female ×:				
Anterior cervical	0.65	0.49	0.86	<0.01
Posterior cervical	1.25	0.94	1.67	0.13
Anterior lumbar	1.09	0.77	1.55	0.62
Posterior lumbar	0.98	0.77	1.25	0.88
Anterior thoracic	0.98	0.61	1.59	0.94
Posterior thoracic	1.03	0.73	1.44	0.87
Combined anterior-posterior	1.12	0.74	1.68	0.60
Four or more levels fused	1.00	0.84	1.20	0.97
Revision surgery	0.91	0.60	1.39	0.67
Degenerative disc disease	1.31	1.08	1.59	0.01
Spinal stenosis	1.15	0.86	1.52	0.34
Spondylosis	1.30	0.89	1.92	0.18
Trauma	0.75	0.60	0.95	0.02

*All covariates and interaction terms are included.

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TABLE E-7 VTE Risk Index Based on Results of the Logistic Regression Analysis with Primary and Secondary Hypercoagulability Excluded*

	Age in Yr				Sex
	18-34	35-49	50-64	65-80	Female
Baseline	−3	0	2	5	−2
			Total A:		Total B:
Approach and surgery					
Anterior cervical	−5	−5	−5	−5	−3
Posterior cervical	−1	−2	−2	−2	1
Anterior lumbar	−2	−1	0	1	1
Posterior lumbar	−3	−3	−2	−2	0
Anterior thoracic	0	1	1	2	0
Posterior thoracic	−1	−1	0	1	0
Combined anterior-posterior	7	6	5	4	1
Four or more levels fused	4	3	3	3	0
Revision surgery	−8	−6	−4	−2	−1
			Total C:		Total D:
Primary Diagnosis					
Degenerative disc disease	−12	−10	−8	−6	2
Spinal stenosis	−6	−6	−5	−5	1
Spondylolisthesis	−6	−7	−7	−8	2
Trauma	11	9	8	7	−2
			Total E:		Total F:
Race/Ethnicity					
Black			3		
Hispanic			1		
			Total G:		
Comorbidities					
CHF			5		
Diabetes			1		
Neurologic disease			3		
Cancer			7		
Obesity			3		
Hypertension			−1		
Renal failure			3		
			Total H:		
Total score (A+B+C+D+E+F+G+H):					

*The total score is calculated by adding together all relevant point values in each category (A through H). If multiple risk factors are applicable, all such point values must be added together; for example, combined anterior-posterior lumbar surgery would include points for anterior lumbar, posterior lumbar, and combined anterior-posterior approach for Total C and Total D. CHF = congestive heart failure.

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TABLE E-8 Comparison of Postoperative VTE Probability According to the VTE Risk Index Point Value in the Two Models

	VTE Probability *(%)*	
Points	Alternate Model	Original Model*
−15	0.08	0.08
−14	0.09	0.09
−13	0.11	0.10
−12	0.12	0.12
−11	0.14	0.14
−10	0.16	0.16
−9	0.19	0.19
−8	0.22	0.22
−7	0.26	0.25
−6	0.30	0.29
−5	0.35	0.34
−4	0.40	0.40
−3	0.47	0.46
−2	0.55	0.53
−1	0.63	0.62
0	0.73	0.72
1	0.85	0.84
2	0.99	0.97
3	1.15	1.12
4	1.33	1.30
5	1.54	1.51
6	1.79	1.75
7	2.07	2.03
8	2.40	2.35
9	2.78	2.72
10	3.21	3.15
11	3.71	3.64
12	4.29	4.20
13	4.95	4.85
14	5.70	5.59
15	6.56	6.43
16	7.54	7.40
17	8.66	8.49
18	9.92	9.73
19	11.35	11.13
20	12.94	12.71
21	14.73	14.47
22	16.72	16.42
23	18.91	18.59
24	21.32	20.96
25	23.94	23.56

*Values in this column are based on the original regression model, prior to exclusion of hypercoagulability.