

Hospital Harm – Postoperative Venous Thromboembolism

Risk-Adjustment Methodology Report (Deliverable 6-3)

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I. Background

The project, titled Patient Safety Measure Development and Maintenance (75FCMC18D0032/75FCMC24F0023), is performed under the Measure & Instrument Development and Support (MIDS) contract for the Centers for Medicare & Medicaid Services (CMS). This report described the rationale and methodology for a risk adjustment model for the Hospital Harm – Postoperative Venous Thromboembolism (HH-VTE) electronic clinical quality measure (eCQM). In this report, we explain risk factors selection, provide the model specification, summarize empirical findings, and present coefficient estimates. We anticipate that the baseline risk adjustment model presented in this report will be refined and updated in future years.

A. Measure specification

The HH-VTE eCQM assesses the percentage of inpatient encounters for adults, 18 years and older, who undergo surgery in an operating room and experience a postoperative VTE during the encounter or within 30 days of the procedure. The HH-VTE eCQM identifies evidence of postoperative VTE events through either (1) documentation of a postoperative diagnostic imaging study followed by either the delivery of therapeutic doses of an anticoagulant within 24 hours after the end of the imaging study, a diagnosis for VTE not present on admission, or placement of an inferior vena cava (IVC) filter within 24 hours after the end of the imaging study; or (2) a diagnosis of VTE and an order or prescription of anticoagulation therapy during a subsequent encounter within 30 or fewer days after the end of the first surgical procedure. Table I.1 summarizes high-level specifications for the HH-VTE eCQM.

Table I.1. HH-VTE high-level specifications

Measure specification element	Specification
Description	The proportion of inpatient hospitalizations for patients aged 18 and older, who have at least one surgical procedure performed inside the operating room during the encounter, and who suffer the harm of a postoperative VTE during the encounter or within 30 days after the first surgical procedure.
Denominator	Inpatient hospitalizations for patients aged 18 and older where a surgical procedure was performed inside the operating room during the encounter.
Denominator exclusion	Inpatient hospitalizations for: <ul style="list-style-type: none"> • Patients with an obstetric-related diagnosis during the inpatient encounter • Patients with a VTE diagnosis present on admission • Patients who had extracorporeal membrane oxygenation (ECMO) during the hospitalization • Patients with acute brain or spinal injury or hemorrhage present on admission • Patients who had a thrombectomy procedure which occurred before or on the same day as the first surgical procedure during the hospitalization • Patients who had intracranial or spinal surgery during the encounter who were discharged less than 5 days after the end of the surgery • Patients who have a duration of stay less than 2 calendar days

Measure specification element	Specification
Numerator	<p>Inpatient hospitalizations for patients with a postoperative VTE within 30 days of the first surgical procedure.</p> <p>Evidence of a postoperative VTE is determined by either Criterion A, B, or C:</p> <ul style="list-style-type: none"> • Criterion A: A qualifying inpatient encounter, excluding encounters where the first surgical procedure was an intracranial or spinal surgery procedure, with a diagnostic imaging study performed during the qualifying inpatient encounter and within 30 days or less after the end of the first surgical procedure performed and at least one of the following: <ul style="list-style-type: none"> – An anticoagulation medication order within 24 hours after the end of the diagnostic imaging study during the qualifying inpatient encounter. An anticoagulation medication order is evidenced by: <ul style="list-style-type: none"> ▪ Enoxaparin (Lovenox) >80 mg per day ▪ Apixaban (Eliquis) >=10 mg per day ▪ Rivaroxaban (Xarelto) >=20 mg per day ▪ Fondaparinux (Arixtra) >= 5 mg per day ▪ Dalteparin sodium (Fragmin)>= 10,000 IU per day; or – A heparin intravenous administration within 24 hours after the end of the diagnostic imaging study, with at least 2 activated partial thromboplastin time (aPTT) heparin therapy monitoring tests or at least 2 anti-factor Xa assays within 35 hours of the start of heparin intravenous therapy administration all which occur during the qualifying inpatient encounter; or – Placement of an inferior vena cava (IVC) filter within 24 hours after the end of the diagnostic imaging study and during the qualifying inpatient encounter; or – A diagnosis of VTE which was not present on admission during the qualifying encounter. <p>OR</p> <ul style="list-style-type: none"> • Criterion B: A qualifying inpatient encounter, where the first surgical procedure was for an intracranial or spinal surgery, and a diagnostic imaging study was performed during the qualifying inpatient encounter and the diagnostic imaging study occurred between 5 days and up to 30 days after the end of the first surgical procedure and at least one of the following: <ul style="list-style-type: none"> – An anticoagulation medication order within 24 hours after the end of the diagnostic imaging study during the qualifying inpatient encounter. An anticoagulation medication order is evidenced by: <ul style="list-style-type: none"> ▪ Enoxaparin (Lovenox) >80 mg per day ▪ Apixaban (Eliquis) >=10 mg per day ▪ Rivaroxaban (Xarelto) >=20 mg per day ▪ Fondaparinux (Arixtra) >= 5 mg per day ▪ Dalteparin sodium (Fragmin)>= 10,000 IU per day; or – A heparin intravenous administration within 24 hours after the diagnostic imaging study, with at least 2 aPTT heparin therapy monitoring tests or at least 2 anti-factor Xa assays within 35 hours of the start of heparin intravenous therapy administration, all of which occur during the qualifying inpatient encounter; or – Placement of an IVC filter within 24 hours after the end of the diagnostic imaging study and during the qualifying inpatient encounter; or – A diagnosis of VTE which was not present on admission during the qualifying encounter.

Measure specification element	Specification
Numerator (continued)	OR <ul style="list-style-type: none"> • Criterion C: A VTE that occurs during a subsequent inpatient encounter and within 30 days or less after the end of the first surgical procedure that occurred during the qualifying inpatient encounter as evidenced by: <ul style="list-style-type: none"> – A diagnosis of VTE during the subsequent encounter; and – Anticoagulation therapy ordered or prescribed during the subsequent encounter.
Numerator exclusion	None

B. Rationale for risk adjustment

VTEs frequently complicates inpatient hospital stays and remain a leading cause of preventable inpatient mortality and unplanned postoperative readmissions (Centers for Disease Control and Prevention [CDC], 2024). Although effective, evidence-based prevention strategies exist, the baseline risk of VTE varies substantially across surgical populations and subpopulations (Nicholson et al., 2020).

CMS recommends that outcome measures be risk-adjusted when the risk of a patient experiencing the outcome is associated with observable baseline risk factors (CMS, 2023). The risk of postoperative VTE is significantly associated with a number of patient characteristics (Henke et al., 2020). The American College of Surgeons National Surgical Quality Improvement Program reports VTE incidence rates ranging from 0.5 percent to 1.6 percent, with elevated rates observed in patients presenting specific risk factors such as malignancy, immobility, advanced age, and major orthopedic procedures (Henke et al., 2020). Hospitalized patients experience increased VTE risk due to both intrinsic patient-level characteristics and procedural exposures (Pastori et al., 2023). To permit fair comparisons among hospitals and their patient populations, the HH-VTE eQOM uses risk adjustment.

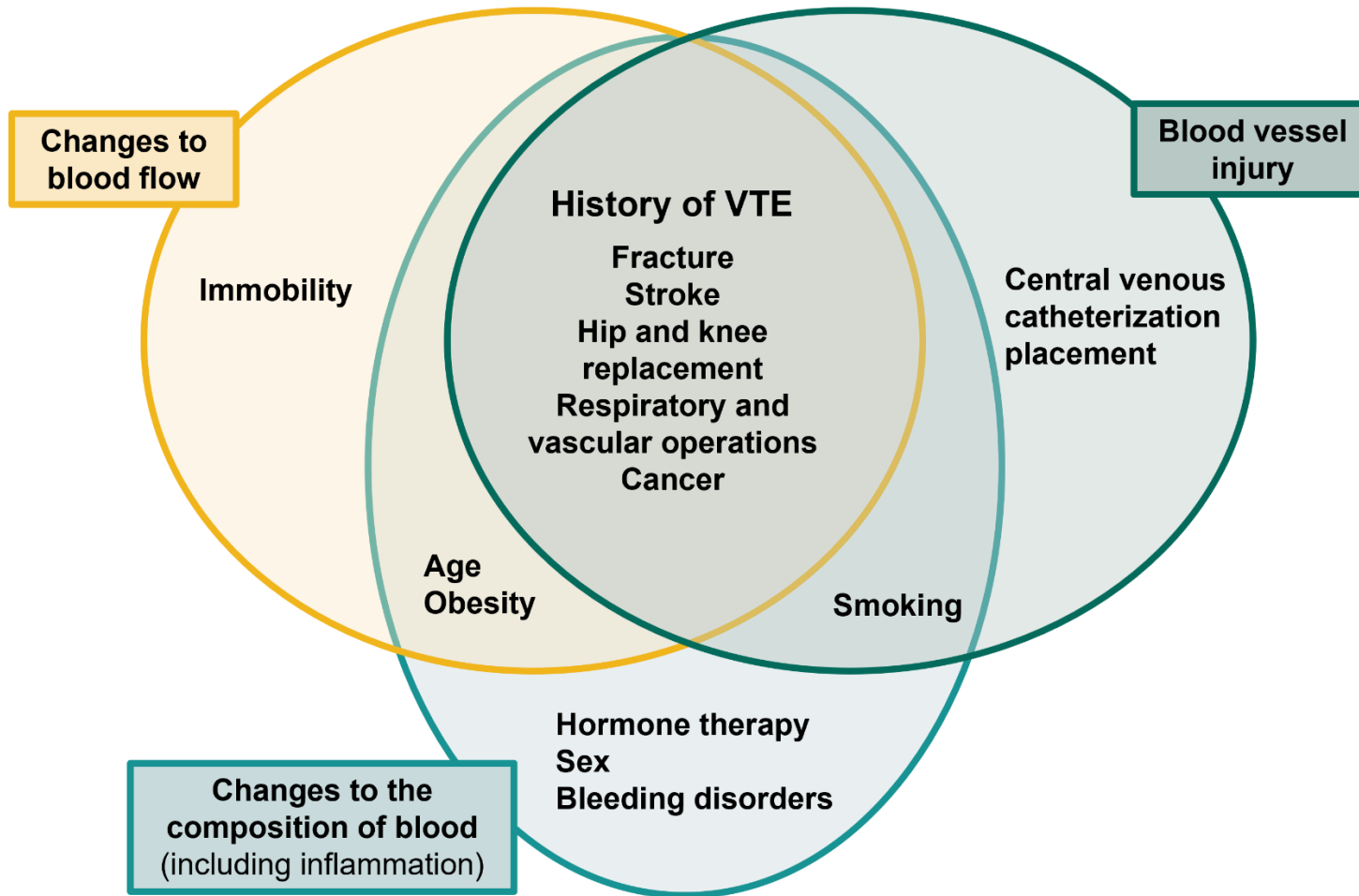
C. Conceptual model

The Virchow triad is a well-established model that describes the conditions that increase the likelihood of a blood clot occurring (Kushner et al., 2024). The three conditions include: (1) a change in blood flow, (2) injury to blood vessels, and (3) changes in the composition of the blood (Kushner et al., 2024). Figure 1 organizes the 14 risk factors we included within the HH-VTE’s conceptual risk model¹ by the conditions each risk factor impacts within the Virchow triad. In the subsequent sections, we describe how we identified these specific risk factors and evidence supporting each factor’s increase risk for VTE.

¹ Note: Although diabetes was initially included in our conceptual model, further in our review of the literature we identified evidence refuting that diabetes is an independent risk factor for VTEs. Therefore, we do not include diabetes in Figure 1.

Figure I.1. Conceptual model for HH-VTE risk-adjustment model

HH-VTE eCQM Risk Factors: Virchow triad



D. Risk factors considered for inclusion in risk model

1. Risk factor identification

We used the following steps to identify risk factors that are associated with greater risk for postoperative VTE, are outside the hospital's control, and are feasible for collection and extraction.

Step 1: Evidence review and initial discussions with technical expert panel (TEP). We gathered an initial set of candidate risk factors through discussions with the Patient Safety Hospital Harm technical expert panel (TEP) and by reviewing the published literature. As part of this first step, we identified candidate risk factors from the Surgeon General's *Call to Action to Prevent Deep Vein Thrombosis (DVT) and Pulmonary Embolism (PE)* and from the modified 3-bucket University California San Diego model referenced in the Agency for Healthcare Research and Quality (AHRQ) report titled *Preventing Hospital-Associated Venous Thromboembolism* (Office of the Surgeon General, 2008; Maynard, 2016). We presented factors we identified through this initial documentation review to the TEP members during a meeting on June 5, 2024. The TEP members recommended reviewing scoring indices to further identify factors for inclusion into the risk-adjustment model. In response, we reviewed the Rogers Score (Rogers et al., 2007), the Caprini Score for Venous Thromboembolism (Caprini, 2010), and an intensive care unit VTE risk assessment (Viarasilpa et al., 2020), and we added factors from these scoring indices to our list of candidate risk factors.

Step 2: Clinical review. We then reviewed the list of candidate risk factors with two clinical subject matter experts (SMEs) on the project team and added or removed risk factors based on their clinical relevance to the outcome and on a hospital's ability to mitigate the risk associated with each factor.

Step 3: Selection of candidate risk factors to include in risk model development. Building on the work conducted during the prior steps, we developed a list of risk factors for potential inclusion in the risk model. We shared this list of risk factors with the TEP and solicited their feedback via a survey. We received feedback from 16 of 25 TEP members. We used this feedback to select a set of clinical risk factors to include in a risk model that we then tested using patient-level data. Table I.2 displays the clinical risk factors tested for potential inclusion in the risk adjustment model as well as the evidence for their potential inclusion in the risk model.

Table I.2. Demographic and Clinical risk factors for VTE included in the risk adjustment model

Factor	TEP support	Mathematica clinical SME support	Surgeon General Report	VTE scoring indices support			
				"3 Bucket" Model In Use at UC San Diego ²	Caprini Score	Rogers Score	ICU-VTE risk assessment
Fractures	X	X	X	High	High		
Hip or knee joint replacement procedures	X	X		High	High		
Vascular operations		X				High	
Respiratory operations		X				High	
Experienced a stroke		X		Moderate	High		
Patients with central venous catheterization placement ³		X			Low for non-ICU patients		High
History of blood clots, either DVT or PE	X			Moderate	Moderate		Moderate
Bleeding disorders	X			Moderate	Moderate		
Age	X				Moderate		
Immobilization	X			Moderate			
Cancer	X	X		Moderate			
Obesity	X		X				
Patients using hormone therapy			X				
Tobacco use	X		X				
Diabetes	X						
Sex	X		X		Low	Low	

AHRQ = Agency for Healthcare Research and Quality; DVT = deep vein thrombosis; ICU-VTE = Intensive care unit – venous thromboembolism; PE = pulmonary embolism; SME = subject matter expert; TEP = technical expert panel; VTE = venous thromboembolism.

² The "3 Bucket" model is referenced in AHRQ's "Preventing Hospital-Associated Venous Thromboembolism" report.

³ Mathematica clinical SME recommended broadening criteria to include venous catheterization placement, regardless of ICU status.

2. Risk factor evidence

In the remainder of this section we review the existing evidence as it relates to each identified risk factor listed in the conceptual model.

a. Demographic risk factors

Age. Age is a well-established factor that influences the risk of postoperative VTE (Anderson et al., 1991; Silverstein et al., 1998; Cushman et al., 2004) in part because advancing age is associated with immobility and age-related physiological changes of blood that promote thrombosis (Akrivou et al. 2022). Evidence shows that patients aged 40 years and older face a significantly elevated VTE risk compared to younger individuals, with the risk approximately doubling with each subsequent decade (Anderson & Spencer, 2003). This association is reflected in the Caprini Score for VTE, which assigns increasing risk for older age groups as a predictor of VTE risk (Caprini, 2010).

Sex. Sex-based differences contribute to measurable differences in the incidence of postoperative VTE events between men and women (Heit et al., 2016). During reproductive years, women experience a two- to three-fold higher risk than age-matched men, likely due to hormonal influences and pregnancy-related factors that promote procoagulant changes in the blood (Scheres et al., 2022). However, after age 50, as estrogen-driven risks decline, men's relatively higher intrinsic VTE risk becomes more evident (Scheres et al., 2022). Scheres et al. (2022) note that greater visceral fat, metabolic dysregulation, and low-grade inflammation in men could be potential contributors to this elevated risk. In both sexes, aging increases clotting factor levels, inflammation, and venous stasis, driving the sharp rise in VTE incidence after age 70 (Scheres et al., 2022).

b. Clinical risk factors

Fractures. Fractures place individuals at high-risk for postoperative VTE events. Fractures trigger blood clot formation because the broken bone ends cause venous endothelial injury, the body enters a post-traumatic hypercoagulable state, and prolonged immobilization slows venous blood flow—together fulfilling all conditions for thrombosis (Hu et al., 2023). Fractures were supported as risk factors for VTEs within both clinical scoring systems and recent literature. The Caprini Score for VTE classifies fractures (particularly of the hip, pelvis, or leg) as high-risk for VTE (Caprini, 2010). Supporting this evidence, Rogers and colleagues (2012) found that in a study of 399 patients, fractures were independently associated with hospitalization for VTE, producing an adjusted incidence rate ratio of 2.81 ($p < 0.001$). The incidence of VTE varies by fracture type, with one study reporting DVT rates as high as 16.6 percent in patients with hip fractures (Pastori et al., 2023).

Stroke. Acute ischemic stroke (AIS) patients are at elevated risk of developing VTE, due to the increased neuroinflammatory response in which T cells interact with activated platelets (Stoll & Nieswandt, 2019). This process—known as thrombo-inflammation—triggers downstream activation of coagulation factor XII, thereby linking post-stroke inflammation to heightened thrombosis and clot formation (Stoll & Nieswandt, 2019). Immobility commonly associated with AIS further increases the risk of VTE (Turpie et al., 2013; Henke et al., 2020). The Caprini Score for VTE classifies stroke within the month of surgery as a high-risk factor for VTE (Caprini, 2010). Supporting this, Garg and colleagues (2021) identified 1,541,685

hospitalizations due to AIS and found that hospitalizations due to AIS had a higher odd of VTE as compared to the non-vascular neurological controls [odds ratio (OR) 1.50, 95% CI 1.40-1.60, $p < 0.001$].

History of VTE. According to Caprini (1991), the increased risk of recurrent VTE in individuals with a prior history of VTE is due to damage caused by previous thrombosis. This damage includes scarring of the vein's inner lining, destruction of venous valves, and reduced fibrinolytic activity, all of which contribute to a higher likelihood of clot recurrence. In an observational study of 1,231 consecutive patients with VTE, 19 percent had at least one prior clinically recognized episode of VTE (Anderson & Spencer, 2003). Furthermore, a case-controlled study found that patients with a history of VTE were approximately eight times more likely to develop a new episode during a high-risk period (e.g., major surgery, prolonged immobility) compared with patients without a history of VTE (Anderson & Spencer, 2003).

Bleeding disorders. The Caprini Score for VTE lists several blood clotting disorders, such as present factor V Leiden and positive prothrombin 20210A, as moderate predictors for VTE (Caprini, 2010). Factor V Leiden and the prothrombin G20210A mutation increase clot risk because they lead to excess thrombin generation, the central enzyme driving fibrin clot formation (Deitcher et al., 2020). Although some bleeding disorders, such as hemophilia, cause a bleeding tendency, a complex interplay of factors can paradoxically increase some patients' susceptibility to thrombotic events like deep vein thrombosis or pulmonary embolism. Badulescu et al. (2025) explains that VTE events, although rare, can occur in patients with hemophilia, despite their bleeding tendency, particularly when additional prothrombotic factors are present. The authors highlight that triggering events such as surgery, immobilization, central venous catheters, or additional prothrombotic risk factors elevate VTE risk in this population.

Immobilization. Immobilization is a well-established predictor of VTE (Anderson & Spencer, 2003; Office of the Surgeon General, 2008). According to Caprini (1991), immobilization contributes to VTE risk by promoting venous stasis, which slows blood flow and leads to venous dilation. Similarly, AHRQ's *Preventing Hospital-Associated Venous Thromboembolism*, recognizes immobility as a well-established risk factor for hospital-acquired VTE (Maynard, 2016).

Cancer. The identification of cancer as a moderate risk factor by the Caprini Score for VTE is supported by literature (Douketis et al, 2000; Hutten et al., 2000). Cancer increases the risk of VTE for several reasons, including (a) cancer cells releasing chemicals that stimulate the body to produce clotting factors, (b) treatments, such as chemotherapy causing blood vessel injury and (c) immobility stemming from feeling ill from cancer and associated treatments (Abdol et al., 2018; Cancer Research UK, n.d.). The *Surgeon General's Call to Action to Prevent Deep Vein Thrombosis and Pulmonary Embolism* (2008), highlights that the incidence of VTE is significantly higher in cancer patients than in non-cancer patients across all major surgical procedures. The report further notes that, without preventive treatment, an estimated 40 percent to 80 percent of surgical cancer patients may develop DVT in the calf veins, while 10 percent to 20 percent may develop proximal DVT (Office of the Surgeon General, 2008). Additionally, four percent to 10 percent of these patients may experience PE, with one percent to five percent of cases resulting in death (Office of the Surgeon General, 2008).

Obesity. The *Surgeon General's Call to Action to Prevent Deep Vein Thrombosis and Pulmonary Embolism* (2008) notes that, for reasons not entirely understood, individuals with obesity are at significantly greater risk for developing DVT and PE (Office of the Surgeon General, 2008). More recent research indicates that

obesity can cause chronic inflammation and impaired fibrinolysis which can increase the likelihood of blood clots (Blokhin et al., 2013). Researchers have identified that individuals with a body mass index (BMI) over 30 have a two- to three-fold increased risk of blood clots, with the risk rising even higher for individuals with a BMI above 40 (Office of the Surgeon General, 2008). Similarly, a study found that among 372,594 patients, VTE incidence increased with obesity severity, rising from 9.5 percent in overweight individuals to 14.4 percent in those with class III obesity (BMI ≥ 40) ($p < 0.001$) (Mahadevia et al., 2024). Lastly, the Caprini Score for VTE includes obesity as a low-risk factor, acknowledging its contribution to VTE risk, particularly when combined with other risk factors (Caprini, 2010).

Hormone therapy. The risk of VTE is elevated in women who receive estrogen-based contraceptives, hormone replacement therapy, or infertility treatment (Lutsey et al., 2023). According to Abou-Ismaïl et al. (2020), estrogen alters the composition of blood by shifting the balance of hemostasis toward a prothrombotic state. It increases levels of several clotting factors (such as factors II, VII, VIII, X, and fibrinogen) and von Willebrand factor, while decreasing natural anticoagulants like protein S and antithrombin (Abou-Ismaïl et al., 2020). Estrogen also influences inflammatory and fibrinolytic pathways, producing changes that make the blood more likely to clot overall (Abou-Ismaïl et al., 2020). The *Surgeon General's Call to Action to Prevent Deep Vein Thrombosis and Pulmonary Embolism* (2008) states that oral contraceptives containing both estrogen and progestin can raise the risk of VTE by two- to eight-fold (Office of the Surgeon General, 2008). Additionally, postmenopausal women undergoing hormone therapy face a higher risk, with large studies indicating a two- to four-fold increase in VTE risk (Office of the Surgeon General, 2008). Recent literature demonstrates that hormone replacement therapy in postmenopausal women is associated with an increased risk of VTE, with the risk approximately doubling compared with nonusers (LaVasseur et al., 2022). Literature also indicates that the route of estrogen administration significantly influences this risk: oral estrogen increases blood-clotting activity, whereas transdermal estrogen has little impact on clotting and is not associated with a higher risk of VTE. (LaVasseur et al., 2022). Topical vaginal estrogen, commonly used to treat local menopausal symptoms, likewise shows no association with thrombosis (LaVasseur et al., 2022). Among progestins, first-generation agents such as medroxyprogesterone acetate carry a higher thrombotic risk than newer formulations (LaVasseur et al., 2022).

Smoking. Recent literature presents mixed findings on whether smoking independently increases the risk of VTE. Smoking harms the lining of blood vessels and makes the blood "stickier," which causes platelets and immune cells to gather more easily (Messner et al., 2014). It also activates the body's clotting system while slowing down the processes that normally break clots apart (Messner et al., 2014). Together, these changes make it easier for dangerous blood clots to form. The *Surgeon General's Call to Action to Prevent Deep Vein Thrombosis and Pulmonary Embolism* (2008) lists individuals who smoke as having a higher risk of VTE. Supporting this, a meta-analysis of 32 studies involving 3,966,184 participants found that the overall combined relative risks (RRs) for developing VTE were 1.17 (95% CI 1.09–1.25) for ever smokers, 1.23 (95% CI 1.14–1.33) for current smokers, and 1.10 (95% CI 1.03–1.17) for former smokers, respectively (Cheng et al., 2013). In contrast, Ageno et al. (2008) conducted a comprehensive meta-analysis to evaluate the association between cardiovascular risk factors and VTE, including smoking. The analysis incorporated data from ten studies comprising over 38,000 participants. The pooled results indicated that smoking was not significantly associated with an increased risk of VTE, with an overall odds ratio of 1.15 (95% CI: 0.92–1.44) (Ageno et al., 2008).

Diabetes. Research into whether diabetes is a risk factor for VTE is inconclusive, with some studies finding either no association or a modest association. Diabetes increases the likelihood of blood clots because chronic hyperglycemia damages the vascular endothelium, enhances platelet hyperreactivity, and elevates procoagulant factors (Shao et al., 2023). At the same time, diabetes impairs fibrinolysis, creating a prothrombotic state in which clots form more readily and are broken down more slowly (Shao et al., 2023). Bell and colleagues (2017) conducted a systematic review of 19 studies and found that the pooled relative risk for the association of diabetes mellitus with VTE was 1.10 (95% CI: 0.94–1.29). Ding et al. (2023) found that diabetes was associated with a modestly higher risk of VTE (OR = 1.27, 95% CI: 1.15–1.41), but this association disappeared after adjusting for body mass index (OR = 1.04, 95% CI: 0.94–1.15). These studies suggest that diabetes is unlikely to play a major role in VTE development.

Hip/knee replacements. Hip and knee replacement surgeries are associated with a high risk of VTE (Office of the Surgeon General, 2008), and consequently the Caprini Score for VTE classifies hip/knee replacement procedures as high-risk factors for VTE (Caprini, 2010). The increased risk for blood clot formation after hip or knee replacements is likely due to immobility and inflammation both prior to and after surgery along with the potential for blood vessel injury during surgery (Santana et al., 2020).

Respiratory and vascular operations. The Rogers Score classifies respiratory and vascular operations—such as thoracoabdominal aneurysm repair, venous reconstruction, and endovascular interventions—as high risk for VTE (Rogers et al., 2007). In developing their risk model, the authors used endocrine operations as the reference group, as these procedures carried the lowest observed VTE risk. They found that respiratory surgeries posed a high risk of postoperative VTE, with an odds ratio of 9.369 compared to endocrine procedures (Rogers et al., 2007). The authors postulated that the elevated risk of VTE is from common postoperative complications such as respiratory failure, which often leads to prolonged immobility (Rogers et al., 2007). Similarly, vascular procedures like thoracoabdominal aneurysm repair showed a significantly increased VTE risk, with an odds ratio of 6.827 compared to patients who undergo endocrine operations (Rogers et al., 2007). Supporting this evidence, Matthay and colleagues (2022) conducted a single-center retrospective study of 1,449 vascular operations and found an overall VTE incidence of 3.4%, with 37% of events occurring after hospital discharge. The elevated risk of blood clot formation after respiratory and vascular operations reflects not only postoperative immobility and inflammation but also the intrinsic characteristics of these procedures, which often involve significant manipulation or injury of major blood vessels that directly promote thrombosis (Agnelli et al., 2004).

Central venous catheterization placement. The ICU-VTE Score, developed by Viarasilpa and colleagues (2020), identified central venous catheterization as high risk for VTE. Their findings contribute to a growing body of evidence that procedures involving central lines can significantly increase the likelihood of thrombotic complications, particularly in hospitalized or critically ill patients. CVC placement can injure blood vessels and restrict blood flow near the catheter and therefore increase the likelihood of blood clot formation (Geerts, 2014). To further support this finding, a systematic review reported among adults with CVC placement an incidence rate of DVT of 2.7 events per 1,000 catheter-days (Teja et al., 2024).

II. Methods

This section describes the data sources used for beta testing, the methods for risk-adjustment modeling, and the assessment of validity and reliability of the risk-adjusted HH-VTE eCQM.

A. Data

We developed and tested the risk adjustment model using patient-level data from Truveta, a large national database that aggregates structured EHR data from 30 health systems across the United States. We selected Truveta for its extensive size and scope, which supports building a risk model that identifies associations between candidate risk factors and postoperative VTE events and is generalizable to the broader hospital population. Using EHR data from 2022 to 2023, we identified 444,518 unique denominator-eligible encounters for the risk adjustment model.

To calculate performance scores and assess the reliability of the risk adjusted measure, we then relied on a smaller sample consisting of EHR data from 100,911 denominator encounters, which we were able to attribute to 34 inpatient hospitals. Table II.1 displays the characteristics of the 34 Truveta hospitals in our analysis.

Table II.1. Characteristics of Truveta hospitals (N = 34) test sites

Number of test sites	EHR	Location
23	Epic	Texas
7	Epic	Oregon
1	Epic	New Mexico
1	Epic	Alaska
1	Epic	California
1	Epic	Washington

Note: The Truveta hospitals were Epic-based and spanned six states, with most in Texas and Oregon.

B. Risk adjustment

1. Model development

We selected the indirect standardization methodology to risk-adjust the VTE measure. The descriptor *indirect* is used because risk predictions are not based solely on the patients cared for by a particular hospital. Indirect standardization involves using patient-level data across all hospitals to estimate the probability of a VTE event for each inpatient hospitalization in a regression model. The risk prediction derived from the larger population is then applied to a hospital’s patient mix, allowing for the calculation of an *expected outcome rate* at the hospital level. The expected outcome rate is defined as a percentage of the patients that would be expected to experience a VTE event based on the characteristics of the patients cared for by the hospital. By contrast, the *observed outcome rate* is the unadjusted observed rate of VTE events at the hospital-level.

The ratio of observed to expected outcomes (O/E) allows a particular hospital’s performance, given its case mix, to be compared to a hypothetical average hospital with the same case mix. A lower ratio indicates lower-than-expected VTE rates or better quality, while a higher ratio indicates higher-than-

expected VTE rates or worse quality. For the HH-VTE eCQM, we multiplied the O/E outcomes ratio by the *reference population rate*, which is the average observed measure rate in the reference population.

Since at the patient level, the VTE outcome is binary (0/1), whether a patient did not or did experience VTE, we estimated a risk-adjustment model using logistic regression. The model predicted the probability of VTE for each patient given their age, sex, and clinical characteristics.

We used the bootstrap resampling method, described below, to validate the risk-adjustment model. This approach offered several advantages, particularly when dealing with potentially rare events. It allowed using the entire dataset for model development and provided a nearly unbiased estimate of predictive accuracy with relatively low variance compared with other validation approaches, such as data splitting and cross-validation (Steyerberg, 2019). We used the following steps to develop and validate the risk-adjustment model.

- First, we developed the risk-adjustment model on the original patient cohort (N=444,518).
- Then we implemented a stepwise logistic regression process with backward elimination of variables, using 300 bootstrap samples derived from the entire measure population via random selection with replacement. The bootstrap resampling method effectively allowed us to obtain 300 samples of the same size as the original measure cohort but with a different patient case mix.
- For each bootstrap sample, we estimated a logistic regression model, including all the candidate risk factors.
- We retained all variables that showed an association with postoperative VTE events at $p < 0.15$ in 70 percent of the bootstrap samples (that is, in 210 out of 300 samples).⁴

We then fitted the following models:

1. A set of univariate models measuring the association between each candidate risk factor and the outcome unadjusted for the other candidate risk factors.
2. A multivariate logistic regression model that captures the effect of all candidate risk factors on the outcome simultaneously, and in which the effect of each candidate risk factor is adjusted for the other variables in the model. We fitted separate multivariate models with and without clinical risk factors:
 - Model 1: Demographic risk factors (age, sex); and
 - Model 2: Demographic and clinical risk factors (age, sex, fractures, hip/knee joint replacement procedures, vascular operations, stroke, central venous catheterization placement, history of VTE, bleeding disorders, age, obesity, hormone therapy use, tobacco use, diabetes, respiratory operations, and cancer).

⁴ The p -value cutoff of 0.15 approximately mimics variable selection based on the Akaike Information Criterion (AIC). To select a candidate risk factor on the basis of AIC, its chi-squared (χ^2) value has to exceed twice its degrees of freedom (df). When considering a predictor with 1 df, such as sex or whether or not a patient has comorbid conditions, this implies $\chi^2 > 2$ with $p < 0.157$.

We evaluated the univariate and multivariate associations between each candidate risk factor and the outcome and assessed whether the odds ratios comparing patient categories were in the expected direction.

To assess model performance, we computed the following summary statistics:

- **Discrimination:** We assessed the model discrimination via a concordance statistic (C-statistic, also known as area under the curve). The C-statistic represents the probability that a randomly selected patient who had the outcome of interest (VTE) had a higher predicted probability of a VTE event compared with a randomly selected patient who did not experience a VTE event. A C-statistic of 0.5 represents random prediction, and a C-statistic of 1.0 represents perfect prediction. Models with C-statistic values between 0.5 and 0.6 are considered to perform poorly, values between 0.6 and 0.7 are considered sufficient, and values above 0.7 are considered good (Šimundić , 2009).
- **Calibration:** We assessed the model performance by computing a Hosmer-Lemeshow test and creating a calibration plot. The Hosmer-Lemeshow test divides the patients into deciles (that is, ten groups with an equal number of patients) based on the expected risk for not experiencing a postoperative VTE event, from lowest to highest risk. The Pearson chi-square statistic summarized the difference between the observed and expected events for each decile.

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III. Results

This section describes the risk-adjustment findings from the testing of the HH – VTE eQM.

A. Multivariate regression, bootstrapping, and discrimination results

We used the risk-adjustment methodology to derive a risk-adjustment model capturing the effect of patients’ demographic and clinical characteristics. We observed a statistically significant effect for patients aged 40-49, 50-59, 70-79, and 80 plus years old compared to the reference group of 18-29 years old. We also observed a statistically significant effect for eight clinical risk factors: bleeding disorders, cancer, central venous catheter insertion, history of VTE, obesity, respiratory operations, stroke, and vascular surgeries. Diabetes had a statistically significant effect on the outcome; however, the odds ratio of 0.840 indicated that there is an associated reduced likelihood of the outcome. The goal of developing the risk model is to identify risk factors that increase the risk for VTE, and therefore diabetes was not included in the final risk-adjustment model. The C-statistic for the risk-adjustment model was 0.692. Table III.1 displays the results of the multivariate regression and bootstrapping analysis.

Table III.1. Assessment of the multivariate regression and bootstrap testing of the risk factors included in the risk-adjustment model (2022–2023)

Risk-factor	Odds ratio	95% CI		p-value	Percent of bootstrap samples with $p \leq 0.15$
Age: 30–39 (vs. 18–29)	1.185	0.937	1.510	0.162	27
Age: 40–49 (vs. 18–29)	1.274	1.027	1.596	0.031	58
Age: 50–59 (vs. 18–29)	1.429	1.165	1.770	0.001	92
Age: 60–69 (vs. 18–29)	1.468	1.202	1.811	0.000	97
Age: 70–79 (vs. 18–29)	1.478	1.211	1.826	0.000	98
Age: 80+ (vs. 18–29)	1.361	1.107	1.690	0.004	83
Sex: male (vs. female)	1.111	1.049	1.177	0.000	94
Bleeding disorders	1.433	1.347	1.524	<0.0001	100
Cancer	1.201	1.133	1.274	<0.0001	100
Central venous catheter insertion	2.437	2.266	2.619	<0.0001	100
Diabetes	0.843	0.795	0.894	<0.0001	100
Fractures	1.032	0.920	1.153	0.588	9
Hip/knee replacement procedures	1.072	0.877	1.298	0.489	10
History of VTE	2.964	2.767	3.172	<0.0001	100
Hormone therapy use	0.948	0.823	1.086	0.445	14
Immobility	0.720	0.607	0.847	0.000	99
Obesity	1.460	1.376	1.548	<0.0001	100
Respiratory operations	2.055	1.884	2.239	<0.0001	100
Stroke	1.302	1.212	1.397	<0.0001	100
Tobacco use	1.033	0.962	1.109	0.370	19
Vascular surgery	1.688	1.314	2.131	<0.0001	96

Source: Analysis of patient data from Truveta (2022–2023).

B. Model specification

We selected clinical risk factors for the final risk-adjustment model if those factors met the following criteria:

1. The odds ratio (OR) from the multivariate analysis indicated statistically significant adverse risk (OR > 1.0, p-value <0.05), and
2. There was p value < 0.15 in 70 percent of the bootstrap samples generated during the bootstrap resampling.

Table III.2 displays the summary of the results from the multivariate regression and the bootstrap resampling, as well as the resulting decision to include in the final risk adjustment models.

Table III.2. Summary of the multivariate regression and bootstrap modeling results to select risk adjustment model variables

Risk-factor	Odds ratio	p-value	Percent of bootstrap samples with $p \leq 0.15$	Inclusion in final risk-adjustment model (Yes/No)
Bleeding disorders	1.428	<0.001	100	Yes
Cancer	1.204	<0.001	100	Yes
Central venous catheter insertion	2.418	<0.001	100	Yes
Diabetes	0.840	<0.001	100	No
Fractures	1.031	0.599	8	No
Hip/Knee replacement procedures	1.075	0.470	11	No
History of VTE	2.932	<0.001	100	Yes
Hormone Therapy	0.950	0.470	13	No
Immobility	0.720	0.000	99	No
Obesity	1.456	<0.001	100	Yes
Respiratory operations	2.046	<0.001	100	Yes
Stroke	1.291	<0.001	100	Yes
Tobacco use	1.036	0.335	100	No
Vascular operations	1.685	<0.001	96	Yes

Source: Analysis of patient data from Truveta (2022–2023).

We found that eight out of the 14 clinical risk factors we tested (bleeding disorders, cancer, central venous catheter insertion, history of VTE, obesity, respiratory operations, stroke, and vascular surgeries) were associated with increased risk of VTE and met the criteria for inclusion in the final risk model. These results are consistent with the findings from the review of scoring indices described in section I.C above (e.g., Rogers score, Caprini score), which found that all of these factors, except for obesity, have an association with either a moderate or high risk of developing VTE.

C. Final risk-adjustment model calibration results

We assessed the performance of the final risk-adjustment model using the C-statistic, Hosmer-Lemeshow goodness-of-fit test, and calibration plot. The model's ability to discriminate between high-risk and low-risk postoperative VTE events, as measured by the C-statistic, was modest (0.692). If a c-statistic is closer to one, this indicates that the model can classify outcomes correctly. Although the model suggested a moderate predictive discrimination, our comparison of observed to predicted probabilities by risk deciles (see Figure III.1) shows that the model is well-calibrated.

The Hosmer-Lemeshow test—a statistical test for goodness of fit and calibration for logistic regression models—divides patients into deciles (i.e., ten groups with equal numbers of patients) based on the expected rate of postoperative VTE events, from lowest to highest. In decile assessment, we should see similar numbers of observations in each decile group and increasing observed rates when we move from low to high deciles. Table III.3 displays the results of the Hosmer-Lemeshow analysis.

Table III.3. Results of the Hosmer-Lemeshow test for the final risk-adjustment model (2022–2023)

Decile	Number of patients	Sum of predicted rates (by decile)	Sum of observed rates (by decile)	Ratio of observed to predicted rates	Chi-square
1	45,917	0.005	0.004	0.857	0.0001
2	43,257	0.006	0.005	0.833	0.0002
3	44,303	0.006	0.006	0.968	<0.0001
4	46,327	0.007	0.007	1.030	<0.0001
5	43,206	0.008	0.007	0.896	<0.0001
6	43,723	0.008	0.008	0.992	<0.0001
7	44,772	0.010	0.009	0.968	<0.0001
8	44,148	0.011	0.012	1.053	<0.0001
9	44,484	0.017	0.019	1.101	0.0002
10	44,381	0.037	0.037	1.015	<0.0001

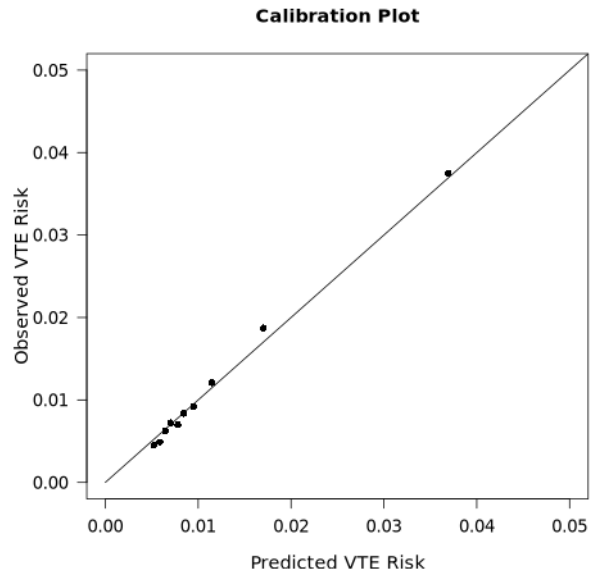
Source: Analysis of patient data from Truveta (2022–2023).

Table III.4 shows an increasing trend in the sum of predicted rates by decile, indicating that the model is adequately capturing the relationship between the predictors and probability of the outcome. The observed-to-predicted rates by decile demonstrate the same pattern. An observed-to-predicted rate of one indicates that the model accurately predicts the outcome for every observation. In this sample, the observed-to-predicted rate is approximately one, particularly for the higher deciles, indicating that the model is more effective at predicting the outcome for patients at higher risk of VTE. While this test allows us to obtain a general understanding of how the model predicts the outcome for patients with different risks, there are limitations to this analysis. These limitations are due to the limited number of risk factors included in the final model, all of which are categorical, and the rarity of the outcome. The limited number of risk factors results in numerous ties and a skewed sample proportion. As such, we interpret these findings with caution, and we supplement them with additional analyses of the model performance, such as the calibration plot described below.

The calibration plot, also known as the calibration curve, visualizes the relationship between the observed and expected values for each decile of patient risk (Figure III.1). If a model is calibrated well, there will not be a substantial deviation from the 45° line of perfect fit or bisector.

The predicted risk in our sample ranged from 0.54 percent in the lowest decile to 3.69 percent in the highest decile. Consistent with the results of the Hosmer-Lemeshow test, the plot indicates a higher agreement between the observed and expected rates of postoperative VTE events for the higher deciles.

Figure III.1. Calibration plot



D. Performance results

We compiled the unadjusted and adjusted performance rates for each hospital (Table III.4 and III.5). The risk-adjusted performance rate for each hospital was computed using the following formula:

$$risk - adjusted\ performance\ rate = \frac{Observed\ measure\ rate}{Expected\ measure\ rate} \times average\ measure\ rate$$

Table III.4. Unadjusted and risk-adjusted performance results by hospital test sites (2022)

Hospital test site	Denominator (n)	Numerator events (n)	Unadjusted score (%)	Risk-adjusted score (%)
1	1,175	10	0.85	0.94
2	754	2	0.27	0.28
3	544	2	0.37	0.38
4	2,369	26	1.10	1.14
5	2,140	15	0.70	0.79
6	64	0	0.00	0.00
7	1,159	16	1.38	1.55
8	5,644	52	0.92	0.80
9	194	1	0.52	0.60
10	439	4	0.91	1.05
11	1,275	13	1.02	1.18
12	1,350	8	0.59	0.59
13	3,042	150	4.93	4.95
14	3,878	21	0.54	0.51
15	2,504	14	0.56	0.51
16	413	2	0.48	0.48
17	1,001	12	1.20	1.42
18	125	4	3.20	3.95
19	143	0	0.00	0.00
20	113	3	2.65	2.88
21	337	1	0.30	0.36
22	536	3	0.56	0.49
23	62	1	1.61	1.80
24	1,124	8	0.71	0.81
25	469	8	1.71	2.02
26	1,460	5	0.34	0.36
27	105	1	0.95	1.40
28	631	3	0.48	0.50
29	938	9	0.96	1.05
30	6,746	54	0.80	0.68
31	205	1	0.49	0.63
32	1,295	13	1.00	0.97
33	1,717	11	0.64	0.69
34	6,252	63	1.01	1.05

Source: Analysis of patient data from Truveta (2022)

Table III.5. Unadjusted and risk-adjusted performance results by hospital test sites (2023)

Hospital test site	Denominator (n)	Numerator events (n)	Unadjusted score (%)	Risk-adjusted score (%)
1	1,342	11	0.82	0.85
2	844	6	0.71	0.69
3	460	4	0.87	0.76
4	2,557	32	1.25	1.18
5	2,157	9	0.42	0.44
6	56	0	0.00	0.00
7	1,100	21	1.91	1.98
8	5,760	58	1.01	0.84
9	147	1	0.68	0.69
10	448	4	0.89	0.92
11	1,301	9	0.69	0.74
12	1,433	14	0.98	0.86
13	2,746	129	4.70	4.51
14	4,047	25	0.62	0.55
15	2,449	14	0.57	0.49
16	413	1	0.24	0.21
17	1,068	5	0.47	0.50
18	161	8	4.97	5.71
19	150	1	0.67	0.72
20	119	3	2.52	2.43
21	285	5	1.75	1.83
22	467	2	0.43	0.37
23	71	2	2.82	3.23
24	1,289	16	1.24	1.34
25	429	2	0.47	0.48
26	1,502	7	0.47	0.44
27	97	1	1.03	1.32
28	611	6	0.98	0.90
29	986	7	0.71	0.66
30	6,716	48	0.71	0.57
31	156	1	0.64	0.79
32	1,259	8	0.64	0.60
33	1,801	14	0.78	0.78
34	6,281	46	0.73	0.69

Source: Analysis of patient data from Truveta (2023).

Across both 2022 and 2023, most hospitals showed modest differences between the unadjusted and risk-adjusted VTE rates. Sixty-six percent of rates across the two years changed by less than 0.1 between the observed and adjusted rates. Twenty-two percent of rates changed between 0.1 and 0.2 and 12 percent changed by more than 0.2.

For the eight scores that changed by more than 0.2, all of these changes resulted in higher risk-adjusted scores than observed scores. This means that factoring in patient characteristics resulted in higher scores (poorer performance) than if the patient characteristics were not factored into the hospital score. These larger shifts were seen in both hospitals with small denominators (less than 200) and those with larger denominators (over 1,000).

IV. Conclusions

The baseline risk model for the HH-VTE measure was conceptually developed, empirically tested, and meets established thresholds for predictive power. First, we created a conceptual risk model to drive downstream analyses which were informed by our project's TEP, published literature, and established VTE scoring indices. This conceptual model consisted of two demographic and 14 clinical characteristics. Next, we empirically tested the risk factors included in the conceptual model using data from 30 health systems and over 400,000 encounters. Through empirical testing, we refined the model to include two demographic (age and sex) and eight clinical characteristics (bleeding disorders, cancer, central venous catheter insertion, history of VTE, obesity, respiratory operations, stroke, and vascular operations). We evaluated the predictive performance of the refined model using the concordance statistic (C-statistic) and observed a value of 0.692, indicating acceptable predictive performance. We also assessed model calibration using the Hosmer-Lemeshow test, which confirmed that the model effectively captured the relationship between the predictors and the probability of postoperative VTE events. These findings demonstrate that the developed model offers a robust and clinically meaningful approach to risk adjustment for the HH-VTE measure, supporting its use in quality improvement programs.

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