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Venous Thromboembolism (vte) Harm Measurement And Risk Assessment In Real-Time Using Electronic Health Records(ehr)

Seyed Mani Marashi
Wayne State University, ez6964@wayne.edu

VENOUS THROMBOEMBOLISM (VTE) HARM MEASUREMENT AND RISK ASSESSMENT IN REAL-TIME USING ELECTRONIC HEALTH RECORDS(EHR)

by

SEYED MANI MARASHI

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Advisor   Date

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DEDICATION

I owe everything in my life to my parents Abbas and Sima; this work is

dedicated to you.

Also, to my beloved wife Mahdokht whose endless love and support made this

possible. And to our newest member of family Elina who gives us motivation and

purpose every day.

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CHAPTER 1 INTRODUCTION

What is Venous Thromboembolism (VTE)?

Venous Thromboembolism (VTE) is a cardiovascular disorder that results from a blood clot (thrombus) that forms within a vein. When a blood clot breaks loose and travels in the blood, it is called a venous thromboembolism (VTE). VTE is the third most common cardiovascular disease after heart attack and stroke[1] with roughly 900,000 instances a year in the US[2]. Centers for Disease Control and Prevention (CDC) suggests that 60,000-100,000 American patients die of VTE in hospitals each year. Their reports also indicate that 10-30% of patients die within one month of diagnosis.[1]

There are two common types of diagnosed VTE disorders:

Deep vein thrombosis: when the blood flow changes or slows down, a deep vein thrombosis (DVT) which is a blood clot forms in the deep veins of the leg.

Pulmonary embolism: when a DVT breaks off (embolizes) and flows towards the lungs, it can partially or completely block one or more arteries (embolism). This can become a life-threatening pulmonary embolism (PE), i.e. a blood clot in the lungs.

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[1] http://www.cdc.gov/ncbddd/dvt/data.html

The abbreviation DVT/PE refers to a VTE in which a deep vein thrombosis (DVT) moves to the lungs (PE or pulmonary embolism).

DVT and PE are serious and lethal conditions that can recur frequently. If these conditions are not diagnosed early, they may lead to long-term complications such as chronic thromboembolic pulmonary hypertension (CTPH) or the post-thrombotic syndrome (PTS).
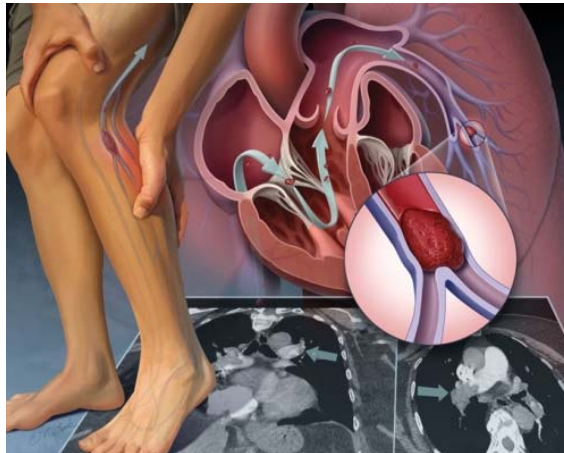
Figure 1 - Deep Vein Thrombosis (DVT) and Pulmonary Embolism (PE)

Symptoms and Diagnosis of DVT/PE

An episode of DVT usually affects one side of the body at a time where the blood clots occur in the large veins located in the lower leg and thigh. The following are the most common symptoms of DVT that occur in the affected parts of the body:

- Swelling

- Pain

- Tenderness

- Redness of the skin

Unfortunately, about half of the people with DVT have no symptoms at all. Pulmonary embolism (PE) can also happen without any symptoms of a DVT. However, signs and symptoms of PE can include:

- Unexplained difficulty in breathing

- Faster than normal or irregular heart beat

- Faster than normal breathing

- Chest pain or discomfort, which usually worsens with a deep breath or coughing

- Anxiety

- Coughing up blood

- Very low blood pressure, lightheadedness, or fainting

DVT is often diagnosed using:

- Duplex ultrasound—This method uses sound waves to evaluate the flow of blood in the veins.

- Venography—If the duplex ultrasound does not provide a clear diagnosis, a venogram- a type of X ray- is used to look at the veins to see if clots are present.

- D-dimer—a blood test that can be used to rule out a clot.

DVT also can be diagnosed using the following, less frequently used tests:

- In many cases, Magnetic Resonance Imaging (MRI) can provide information that would not show up on an x-ray. This test is being used more frequently to diagnose DVT.

- A computed tomography scan is a special type of x-ray that can provide pictures of structures inside the body; however, this test is rarely used to diagnose DVT.

Tests to find the location of and damage to the lungs caused by a PE include:

- Computerized Tomography (CT scan) of the lung: a special type of x-ray that can provide pictures of structures inside the body.

- Pulmonary ventilation or perfusion scan: a special test that looks at how the lung is working and if it is getting enough blood.

- Pulmonary angiogram: the injection of a dye into the heart and then an x-ray to look for clots in the lung.

Unfortunately, there are other conditions with symptoms similar to those of DVT and PE. For example, muscle strains and swelling of veins close to the skin (superficial veins) can produce the same symptoms as DVT. Heart attack and pneumonia also produce symptoms like those of PE. Therefore, it is difficult to diagnose either condition without the aforementioned tests.[2]

Naturally if a patient is admitted to the hospital with symptoms associated with DVT/PE, depending on the situation, the doctors could start treatment with anticoagulants while ordering and waiting for the imaging test results.

Risk Factors for Venous Thromboembolism (VTE)

Although VTE episodes can happen in men and women of various races and ethnicities at any age, there are certain factors that increase the likelihood of VTE instances. DVT/PE episodes are most common in the following circumstances:

- Patients that undergo major surgery (general surgery as well as orthopedic surgery)

- Cancer patients (especially at those at advanced levels of cancer)

- Patients with autoimmune disorders (e.g. lupus)

- Patients with multiple trauma

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[2] CDC Website: http://www.cdc.gov/ncbddd/dvt/diagnosis.html

- Patients with fractures in pelvis, hip, or long bones

- Hospitalized patients

- Paralyzed patients

Other triggers of DVT/PE that are specific to women are pregnancy and using oral contraceptives or hormone treatments for menopause symptoms. DVT/PE risk is greater for pregnant women if they are pregnant with twins or have other medical issues such as cancer or serious infection during their pregnancy. VTE risk will also increase as the maternal age increases.

It is critical for medical professionals to take preventive measures when the aforementioned factors exist. However, there are additional factors that are not as critical but a combination of two or more of them can justify preventive treatment. These factors are listed below:

- Thicker than normal blood

- Previous episodes of VTE

- Obesity

- Age of 40 years old or more (most common in adults 60 and older)

- Family history of VTE

- Genetic conditions that increase the chance of blood clotting

Prevention and Treatment of DVT/PE

VTE incidents are often preventable at hospitals through risk assessment techniques. Healthcare professionals can often discern the risk of VTE incidence by collecting a patient's information such as previous episodes of VTE, age, weight, life style, family history, and medications. By assessing the risk of VTE and identifying high-risk patients, they can prevent VTEs by stopping the developments of blood clots in these patients. According to the American Heart Association (AHA), "adequate prevention measures in high-risk patients can prevent VTE in one of 10 patients"[3]. Therefore, VTE prevention is highly beneficial for public health because of its potential for saving patients' lives and decreasing healthcare costs.

Two ways of preventing and treating DVT are using medication or using compression devices. It is also advised that patients that undergo surgery get up quickly from bed after the surgery. Treatment through medication includes receiving anticoagulants (blood thinners). Although these medications are called blood thinners, they do not actually make the blood any thinner. They target the clotting process of the blood and prevent the clots from getting larger. Another option is using strong clot busters to break up the clots. The most frequently used medications are heparin, low molecular weight heparin (LMWH), and warfarin. As

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[3] AHA Website: http://www.heart.org/HEARTORG/Conditions/VascularHealth/VenousThromboembolism

a side effect, these medications can cause bleeding; therefore, anyone taking them must be monitored to prevent unusual bleeding.

- Heparins

    Usually, treatment of a clot starts with heparin. Heparin is a powerful anticoagulant and is either given through Intravenous or IV (a needle placed in the vein) or administered through an injection to stop clotting more quickly. Since high doses of heparin can cause bleeding, heparin is usually administered only in a hospital.

- Low Molecular Weight heparins (LMWH)

    Although LMWH is similar to heparins, it is made from shorter chains of polysaccharide. LMWH is administered through an injection under the skin (subcutaneous or shortly sub-q). People who take LMWH do not generally require frequent monitoring or blood tests; therefore, they can take the medication while at home.

- Warfarin

    Warfarin (Coumadin™) is a medicine that is taken orally. Since warfarin takes some time to become effective, it usually is begun while a person is taking other medications to stop clotting. Once it reaches an effective level, patients can stop other medications and take only warfarin, but they need to have regular blood

tests to ensure they are not at risk of bleeding. Warfarin can have interactions with many drugs or foods; hence, consultations should be made to ensure the safety of the patient.

- Compression stockings

    Graduated compression stockings are recommended from time to time to prevent DVT and reduce swelling and pain.

- Surgery

    In severe cases, clots might need to be removed surgically. To prevent clots from traveling towards the lungs, a filter is placed in the inferior vena cava which is the body's largest vein. In other procedures, large blood clots could be removed from the vein, or clot busters could be injected in the vein or lung artery.

Other medications used for treating DVT are tablets such as Apixaban, Dabigatran, Rivaroxaban, and Edoxaban. Thromboprophylaxis (i.e. heparin / enoxaparin) is also recommended for non-pregnant patients without contraindications (major bleeding, low platelets, creatinine clearance < 30 mL/min) who are >18 years[3].

Pulmonary embolism is a serious problem and requires emergency treatment. In more severe or life-threatening PEs, thrombolytics, which are medications such as

a tissue plasminogen activator (TPA) that can dissolve the clot, and anticoagulants that prevent more clot build-ups should be used. Sometimes surgery will be needed for patients who are at greater risk of a new PE.[4]

Policymakers such as US Surgeon General, the Centers for Medicare and Medicaid Services[5], and the National Quality Forum[6] have deemed VTE a major threat to patient safety. Therefore, there are numerous programs funded by all sorts of organizations (Government based, Insurance companies, etc.) that are aiming to help reduce VTE incidents at hospitals. Needless to say, the first step to achieving this goal and improving the quality of care is to measure the instances of VTE accurately and in a timely fashion.

Measuring DVT/PE Rates

Historically, DVT/PE rates for inpatients has been measured using administrative or billing data based on a modified version of Agency for Healthcare Research and Quality (AHRQ) PSI#12. Patient Safety Indicator or PSI#12 is one of the components of PSI#90 which was defined by AHRQ as a composite measure to assess patient safety. PSI#90 includes the following indicators which contribute to the composite indicator through weights assigned to each indicator:

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[4] CDC Website: http://www.cdc.gov/ncbddd/dvt/treatments.htm
[5] Centers for Medicare and Medicaid Services. Press release, April 14 2008. http://www.cms.hhs.gov
[6] National Quality Forum. Press release, May 15 2008. http://www.qualityforum.org

- PSI #03 Pressure Ulcer Rate

- PSI #06 Iatrogenic Pneumothorax Rate

- PSI #07 Central Venous Catheter-Related Blood Stream Infection Rate

- PSI #08 Postoperative Hip Fracture Rate

- PSI #09 Postoperative Hemorrhage or Hematoma Rate

- PSI #10 Postoperative Physiologic and Metabolic Derangement Rate

- PSI #11 Postoperative Respiratory Failure Rate

- PSI #12 Postoperative Pulmonary Embolism or Deep Vein Thrombosis Rate

- PSI #13 Postoperative Sepsis Rate

- PSI #14 Postoperative Wound Dehiscence Rate

- PSI #15 Accidental Puncture or Laceration Rate

By AHRQ definition, PSI#12 applies only to post surgery patients. Henry Ford Health System (HFHS) uses a modified version of the PSI#12 for all patients including both surgical and medical patients.

The validity of using AHRQs PSI#12 to measure DVT/PE harm has been discussed in many papers in the past decade; however, there is considerable variability in the reported results. Birman-Deych, et al. used billing data of arterial fibrillation patients and reported a sensitivity of 61% and a positive predictive value (PPV) of

72% with negative predictive value (NPV) and specificity of 99% [4]. White, et al. reported 80% sensitivity and 31% positive predictive value focusing on pregnant patients at risk of getting DVT/PE [5]. Among the papers that focused on surgery patients, Henderson, et al. found the sensitivity of the PSI#12 to be 87% with a PPV of 55% [6]. In other studies, Zhan, et al. reported PSI#12's sensitivity and PPV of 74% and 35% [7], and Romano, et al. reported it to be only 56% sensitive with a PPV of just 22% using Veterans Affairs patient data [8]. Among the papers that applied the PSI#12's logic to medical and surgery patients, Heckbert, et al. reported sensitivity of 86% and PPV of 75% [9] while Cushman, et al. reported PPV of 79% [10], and White, et al. reported a better performance for the PSI#12 with sensitivity and PPV of 96% and 79% [8]. Leibson, et al. reported a lower sensitivity of 74% with the PPV of only 35% [11], and finally, White, et al. found the PSI#12's NPV to be at 95% [12]. Table 1 summarizes this comparison.

Table 1 - PSI#12 Validation - Summary

Author(s)	Patient Population	Sensitivity	PPV	NPV
Birman-Deych et al., 2005	Medicare beneficiaries aged 20 to 105 years who had atrial fibrillation.	61%	72%	99%
White, Brickner, & Scannell, 2004	VTE either during pregnancy or the 6-week postpartum period	80%	31%	
Henderson et al., 2009	Post-Surgery	87%	55%	
Zhan, Battles, Chiang, & Hunt, 2007	Post-Surgery	74%	35%	
Romano et al., 2009	Post-Surgery VA Patients	56%	22%	
Heckbert et al., 2004	Medical and surgery	86%	75%	
Cushman et al., 2004	participants of the Atherosclerosis Risk in Communities study and the Cardiovascular Health Study	62%	79%	
White et al., 2009	Data from 47 Hospitals Participated in PSI Validation Project	79%	44%	
Leibson et al., 2008		74%	35%	
White, et al., 1998	Patients After primary hip and primary knee arthroplasties	100%	68% To 100%	95%

Although using billing data for measuring DVT/PE harm is cheap, and the data is readily available, this method comes with a few shortcomings. As mentioned above, using billing data will provide widely varying levels of accuracy depending upon the co-morbidity. In addition, there are significant delays from the time of diagnosis and treatment until the billing data becomes available for analysis. For example, an analysis of 9 months of billing data at Henry Ford Health System showed that it took an average of three weeks after discharge for the billing data to become available. In addition, in 21% of the cases, this process took a month or

longer. Figure 2 shows the distribution of the time that it took to code and bill a

hospital account after discharge.
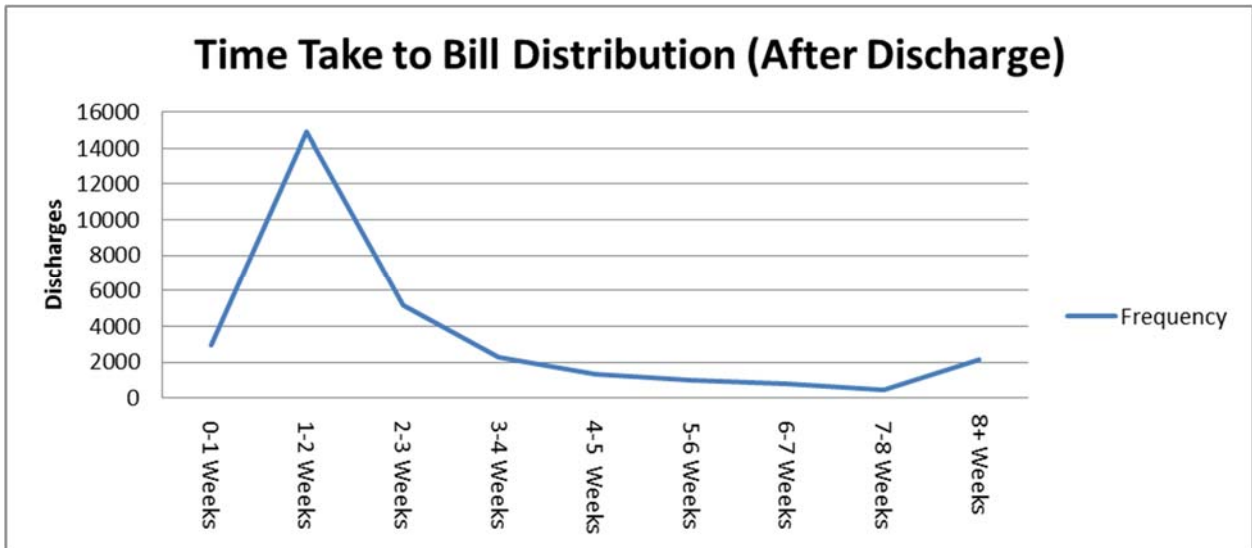
Figure 2 - Distribution of Time to Code a Hospital Account after Discharge

The impact of a lag caused by using billing data can be shown using a hypothetical

hospital stay of three months. If a VTE episode happens in week one of a 3 months

stay, the VTE case will only appear in the billing data 3.5 months after the incident.

The total delay in studying an incident includes the time from onset until discharge

plus the billing processing delay as illustrated in Figure 3.

Hypothetic Length of Stay (3

| One | One | Average time to bill (3 |

PSI#12 lags behind (3.5

DVT/PE

Earliest   time

PSI#12 can detect

Hospital
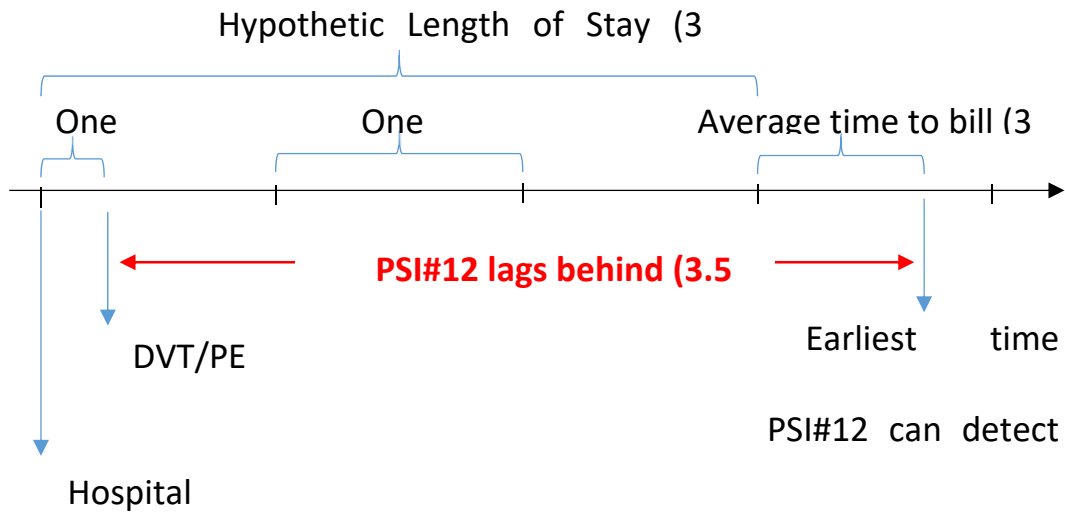
Figure 3 - Demonstrate how PSI#12 lags for a hypothetical DVT/PE episode

The unavoidable extended lag reduces the potential value of this data in improving care and educating medical personnel about patient safety. Imagine a medical doctor talking to his/her interns or residents who review cases of DVT/PE. There is a huge difference between reviewing cases of DVT/PE that happened last month in the hospital and DVT/PE episodes that happened over the weekend to patient XYZ in room 1234 in bed B. In the latter situation, they can quickly review medical charts that are current and discuss why it happened and how to it can be prevented in similar situations.

In this research, the aim was to overcome the shortcomings of measuring the VTE incidents with billing data by developing a near real-time VTE harm

measurement using Electronic Medical Records. A VTE risk assessment model was

also developed in the EHR that is capable of real-time patient risk assessment based

CHAPTER 2 NEAR REAL-TIME VTE HARM MEASUREMENT USING EHR

In this chapter, we first discuss some of the main challenges and limitations that bear on using Electronic Health Records in the identification of DVT/PE instances. Then, we introduce our proposed model and discuss how this model overcomes the challenges of the historical model. After that, a comparison of the results of the PS#12 model and our proposed model will be presented. Finally, we conclude the discussion by linking our model to practice and suggesting how it can be used at the hospital.

Using EHR to measure DVT/PE Harm

Limitations and challenges of using EHR to find DVT/PE harm

Challenge 1: First, it is essential to note that each EHR implementation and rollout in diverse hospitals is different from another. Even when different hospitals use the same software product from a specific vendor, the implementation could still be different. They often customize the system, turn the functionalities on or off, or choose to prioritize implementations of modules differently. The main tool to diagnose DVT/PE is imaging tests such as Doppler, Duplex or Chest CT Scan for PE. In our study at HFHS, like many other hospitals, the imaging results are not yet a part of the EHR system. The results are stored in another system as image files, and hence not searchable or extractable. Having the imaging results in the EHR

system will make a huge difference in identifying DVT. Until that time, one of the messages this research tries to convey is that current use of partial information in EHR could still produce real time results that are significantly better than what is currently available through billing.

- Challenge 2: In theory, reporting could be done in real time using EHR; however, it is not value-adding in practice in the case of DVT/PE harm measurement. In addition, giving physicians and nurses access to run the report on-demand could overload the live system which is needed in real-time to save lives. Instead, the model we develop will run on a backup of another backup of the live system which lags by 24 to 48 hours depending on the time of day the incident happened.

- Challenge 3: One other issue was to identify medications used for DVT/PE treatment and find a way to distinguish between the treatment of clots and prophylaxis dosages of the medications to prevent clots. An analysis found that the medications used for treating DVT/PE overlap with many other problems, conditions and procedures. These include as Cerebrovascular Arrest, Arterial Fibrillation (A-fib), Mechanical Valve Replacement, Arterial Valve Replacement, Left Ventricular Assisted Device (LVAD), Extracorporeal Membrane Oxygenation (ECMO), Nonischemic Cardiomyopathy (NICM) and so on. Because these

treatments are not unique to DVT/PE harm, one cannot call the administration

these medications an indication of DVT/PE harm.

- Challenge 4: Another challenge was to distinguish between harm, "at risk" of

  harm and "suspected" harm. At HFHS, a problem list is used in the EHR. When

  doctors order medications or procedures, they must select one or more specific

  problems from the problem list that they have identified in the patient.

  Unfortunately, when in doubt, the doctors specify a problem to order the

  diagnostic tests or medications for treatment; however, if the results come back

  as negative, they should stop the treatment order and remove the problem

  from the patient's records. Preliminary analysis showed that this updating is not

  always followed. The other issue arises when a patient is at risk of the problem

  but does not yet have a DVT. Doctors will select DVT as the problem on the list

  and order prophylaxis dosage of the treatment but this data point needs to be

  weeded out by a harm identification model.

- Challenge 5: One critical concern was to distinguish between pre-existing and

  hospital acquired harm. This can potentially make a significant difference for the

  hospital in terms of the money received for treatment of the patient. Depending

  on the case, if the problem is pre-existing to admission, the hospital can be extra

  compensated for the treatment of an illness with complication or with major

complication. This is because rates for treating conditions are higher when conditions are labelled "with complication", which can add more than $1,500 to the bill. However, if this happens inside the hospital, the hospital would be accountable for the extra treatment of the patient and the resulting expenses. There is a field in the problem list to specify if a problem was present on admission (POA) or not. Preliminary analysis and studies showed that this data field is not reliable. Therefore, other methods were needed to determine if DVT/PE was present upon admission.

- Challenge 6: Another task was to distinguish between thrombosis of other veins versus deep veins in the EHR. There are cases in which the physician suspects that the patient who has been admitted with pain and swelling in their legs has a DVT. The doctor immediately adds this to the problem list and orders imaging tests and starts the treatment. The imaging test may then reveal that it was, in fact, a case of a superficial vein thrombosis and not a deep vein thrombosis. Nevertheless, since it is still a thrombosis in a vein, they do not stop the treatment. This is an extremely hard case to identify, because it was categorized as a DVT and treated as a DVT; however, it was not a DVT. The only way to find these cases is to read the results of the imaging test which are not accessible through the EHR.

- Challenge 7: There is need for a gold standard to reach a final diagnosis for each

  case. Chart reviews were selected as the gold standard but they are expensive

  and time consuming to carry out. Experienced staff must dedicate precious time

  to do chart reviews which is highly variable in length. Each chart review can take

  from a few minutes up to a few hours. An experienced nurse can complete an

  average of one chart review per hour. This limits our ability to select a

  reasonable sample size for this study.

Developed model to identify cases of DVT/PE harm using EHR

DVT/PE treatment options were identified through preliminary studies and

meetings with physicians inside HFHS. The following is a summary of the

medications and their dosages that are used in HFHS to treat DVT/PE;

- Heparin IV: 25,000 units

- Argatroban: any dosage

- Enoxaparin (Lovenox): 40 mg if given at least Bi-Daily or >40 mg at any

frequency

In the absence of diagnostic imaging results, a procedural logic was developed

to identify DVT/PE harm. The logic started out simple. If a DVT/PE problem is added

to the problem list of a patient during a hospital stay, and then they receive

treatment dosages of the above medications, it should mean that the patient had

an episode of DVT/PE while in the hospital. However, as pointed out earlier, the problem list has accuracy problems and many of the medications are also used for patients with heart problems. Another addition to our identification model is checking to see if any imaging procedures were ordered for the patient.

To find out if the problem was present on admission or not, we looked at the time when the patient first received the treatment. In theory, there should be a threshold for the time it takes from the moment of admission until the time a patient receives treatment dosages of the listed medications that best identifies whether there was a pre-existing condition of the DVT/PE, POA. For preliminary studies, 24 hours was selected as the threshold. If a patient had DVT/PE selected on the problem list and received the treatment within the first 24 hours of admission, the logic classified it as a pre-existing DVT/PE. However, if the treatment started more than 24 hours after admission to the hospital, the proposed logic labeled it as a hospital-acquired harm.

Figure 4 shows the original comprehensive logic that was developed to be tested for validity.
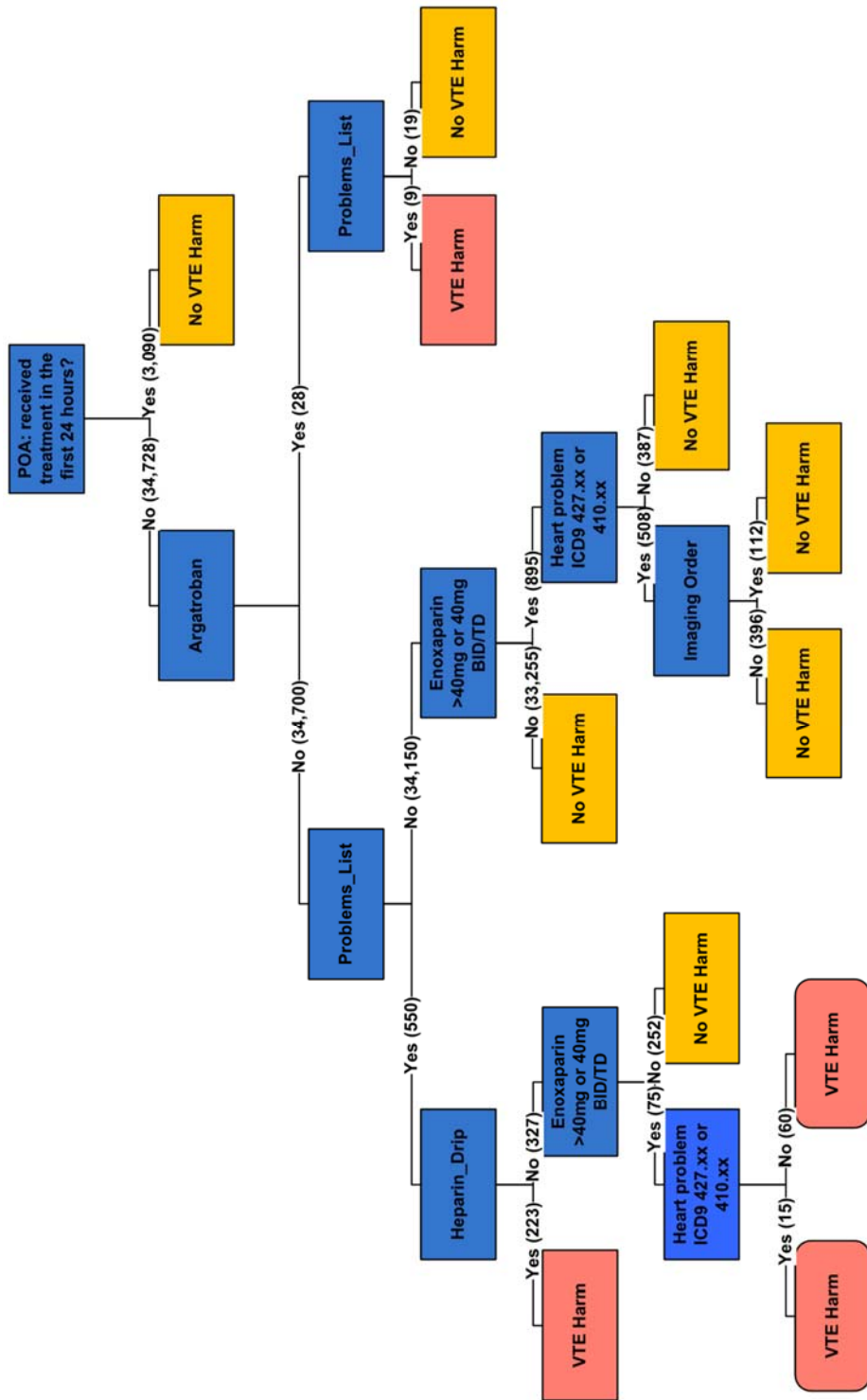
Figure 4 - Original Comprehensive Logic for finding VTE instances

The above figure illustrates the decision logic with the number of cases in each category in parenthesis (till 8/19/2014). The first node checks to see whether a patient received any treatment within the first 24 hours or not. If they received one, the model identifies them as present on admission VTEs. Then it checks to see if the patient received any Argatroban treatment or not. Argatroban treatment was placed near the top since there are only a few other problems that have treatment overlaps with VTE using Argatroban. Other decision nodes that were also considered include any imaging study orders (such as venous doppler, venous duplex, CT scan of chest or pulmonary ventilation (V) and perfusion (Q) or VQ scans), and existence of heart problems that could have Enoxaparin treatment overlaps.

Final model

Figure 5 illustrates the final model showing three selected main indicators of harm. To check the validity of the model, a stratified random sample of 434 cases was selected and analyzed. Four experienced nurses were in charge of the blind sample chart reviews. They were provided with the ID of the patient and the hospital stay that needed to be reviewed, identified by admission and discharge time. Any patient younger than 18 years old was removed from the study. Since

the results were to be checked against the modified PSI#12 method, any hospital account that was not coded by billing was excluded from the study as well.

After the analysis and chart reviews, it was confirmed that 24 hours was the threshold that created the best cut-off for identifying the POA condition. In no case was DVT/PE found to be present on admission and yet, the patient started the treatment after 24 hours. Furthermore, neither type of the VTE treatment (Argatroban, heparin drip, Enoxaparin, etc), existence of any imaging study or present heart problem made any improvements in the performance of the model and hence were removed from the final model.

The model first looked at the problem list. If the DVT/PE was added to the problem list in that episode, and if the patient had received treatment after the first 24 hours from admission, this model calls it a DVT/PE case.
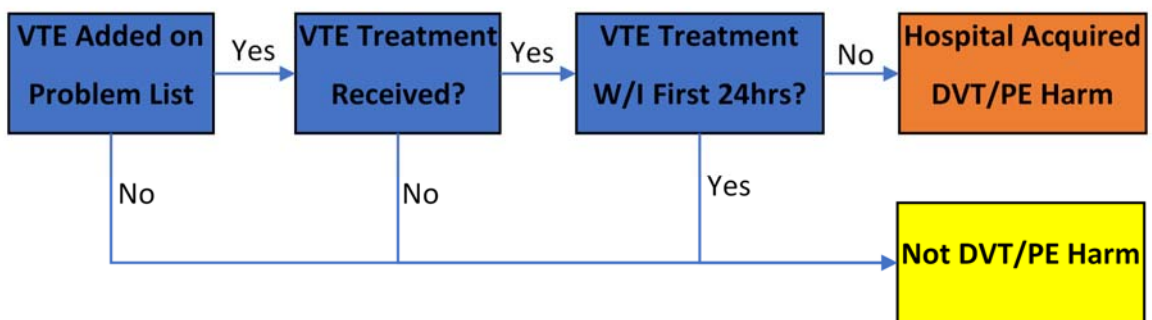
Figure 5 - Simplified and Final Model

Findings and comparison of the results with the current method

Table 2 summarizes the results of the experiment. Asterisk-marked (single or double) cells indicate results significantly different from the ones obtained for the modified PSI#12 using 1-α=0.95. Our proposed logic is more than twice as sensitive as the current PSI#12 (84% vs only 38%). It also outperforms the PSI#12 in Negative Predictive Value (NPV) (99% vs. 95%). However, PSI#12 showed slightly better results than the proposed logic for Positive Predictive Value, PPV and specificity. However, the differences were not statistically significant in both cases.

In comparison, modified PSI#12 found 15 fewer true VTE cases (27 vs 12) which are all false negatives. However, the proposed logic found 8 more false positives than the modified PSI#12 (12 vs 4). The main error was that the model labeled a case as DVT/PE and harm when, in fact, the illness was present on admission. Two cases had a history of both DVT and PE, three cases had a history of DVT and in one case the patient was admitted with the history of PE. Treatment of other veins as DVT resulted in 3 cases of false positives. Prophylaxis for DVT, prophylaxis for PE, ruling-out DVT and ruling-out PE each generated one false positive case for a total of 4 more false positives.

Figure 6 gives another perspective of how our logic model, the modified PSI#12 and the chart review results compare to one another using a Venn diagram. In the

Venn diagram, each circle represents a method of identification of DVT, and the numbers inside a circle are the number of cases of harm identified by that method. For example, number 10, which is covered by all three circles, represents 10 cases of VTE harm that were identified by all three methods. Any number outside the "Actual" circle is considered a false positive, either identified by PSI#12, the proposed logic model or both. Of the false positives, two were shared by both the logic model and PSI#12. Two were unique to PSI#12 and 10 were unique to the logic model.

Table 2 - Results of the Developed Model and the alternatives of the model

Modified PSI#12 (Apply PSI#12 to Both Surgical and Medical Patients)			
Sensitivity:	38% (95% CI=21-54%)	Positive Predictive Value:	75% (95% CI=54-96%)
Specificity:	99% (95% CI=98-100%)	Negative Predictive Value:	95% (95% CI=93-97%)
Proposed Real-Time Logic:			
Sensitivity:	84% (95% CI=72-97%) **	Positive Predictive Value:	69% (95% CI=55-84%)
Specificity:	97% (95% CI=95-99%)	Negative Predictive Value:	99% (95% CI=98-100%) **
Alternative Logic: Receiving Meds and No Heart Problem			
Sensitivity:	72% (95% CI=56-87%) **	Positive Predictive Value:	15% (95% CI=9-21%) *
Specificity:	67% (95% CI=63-72%) *	Negative Predictive Value:	97% (95% CI=95-99%)
Alternative Logic: Only Problem List			
Sensitivity:	94% (95% CI=85-100%) **	Positive Predictive Value:	38% (95% CI=27-49%) *
Specificity:	88% (95% CI=84-91%) *	Negative Predictive Value:	99% (95% CI=99-100%) **
Alternative Logic: Ignoring Problem List			
Sensitivity:	88% (95% CI=76-99%) **	Positive Predictive Value:	23% (95% CI=15-30%) *
Specificity:	76% (95% CI=72-80%) *	Negative Predictive Value:	99% (95% CI=97-100%)
Alternative Logic: Ignoring POA condition (Receiving Treatment in the First 24hrs of Admission)			
Sensitivity:	91% (95% CI=81-100%) **	Positive Predictive Value:	49% (95% CI=36-62%)
Specificity:	92% (95% CI=90-95%) *	Negative Predictive Value:	99% (95% CI=98-100%) **

  * Worse than the corresponding value for modified PSI#12- Statistically significant (1-α=0.95)

  ** Better than the corresponding value for modified PSI#12- Statistically significant (1-α=0.95)
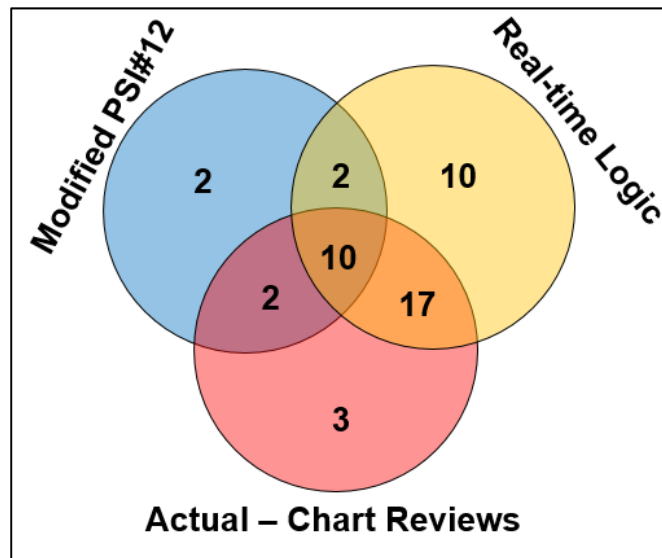
Figure 6- Compare three methods – Venn Diagram

A few WHAT-IF scenarios were also evaluated to determine what happens if all the information used in the proposed model was not accessible. The results of this scenario analysis are summarized in Table 2. Starting from the bottom of the table, if the first administration time of VTE treatment was not accessible, specificity would decline (91% and the number of false positives would increase from 15 to 30). Not surprisingly, this version of the model will often incorrectly categorize pre-existing VTE cases as harm occurring in the hospital.

If the problem list data was not accessible for any reason, the judgment could be made using treatment data and the POA condition. In that case, PPV and specificity suffer significantly (only 23% and 76%). Not surprisingly, the number of false positives significantly increased to 96 cases. This happens because the treatment overlaps with many other conditions.

If only the problem list was used for measuring VTE harm, again PPV and specificity would suffer (38% and 88%) with 49 false positive cases. This number of false positives was mainly due to having many cases of patients being "at risk" of VTE or thrombosis of other veins and receiving "treatment" dosages of selected anticoagulants when, in fact, the patient did not have DVT.

If just receiving the treatment was used to identify VTE cases, this would have to be coupled with a filter to eliminate patients who had cardiac dysrhythmia or acute myocardial infarction. PPV would have declined dramatically to only 15% with a specificity of 67%.

Figure 7 depicts how the two methods of DVT/PE harm measurement, Billing and the Logic Model compare to each other over 14-month period. The Y axis represents number of VTE harm instances per 1000 patient days. The red dotted line is the expected real harm rates calculated by interpolating the numbers from the two methods using the over/under reported proportions obtained in the chart

reviews. From the chart reviews, PSI#12 and our logic respectively found 16 and 39

cases as compared to the 32 cases that were found in chart reviews. From these

figures, we can estimate that PSI#12 finds 50% fewer DVT/PE cases while our logic

model finds 21% more.
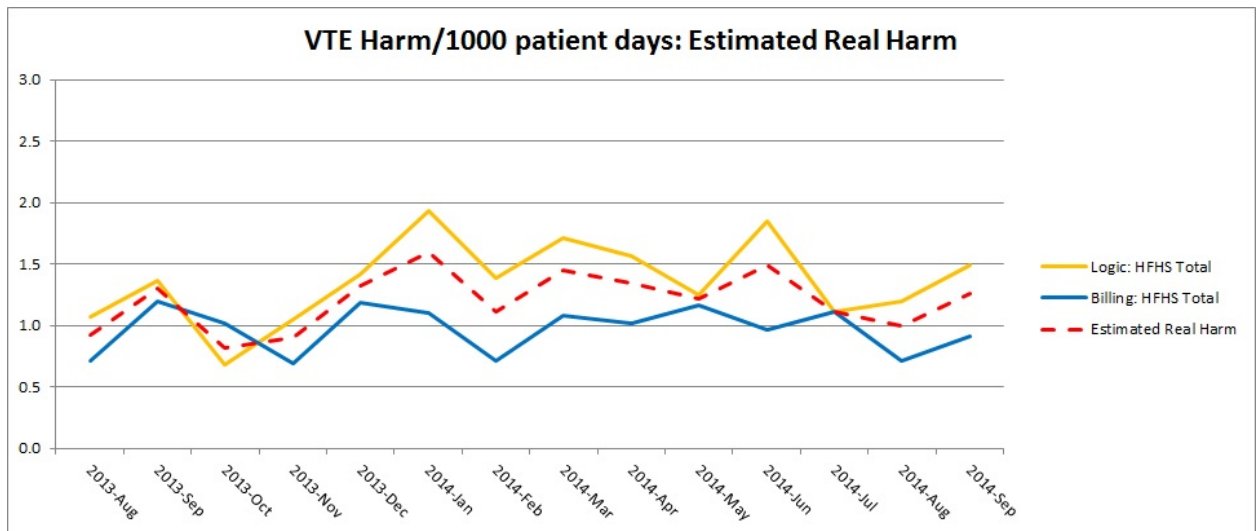
Figure 7 – Compare Three Methods - Trends

Link to practice and how the model could be used

With the predictive value of the model verified, we investigated how

implementation of the model might impact practice. One use of the model would

be to improve diagnosis documentation. For example, a DVT/PE problem should be

removed from the problem list of the patient if the DVT/PE has been ruled out by

the imaging tests; however, chart reviews revealed that this record update does

not always happen.

This model also can help improve resident education program. Senior physicians can review VTE cases with their residents soon after each instance of VTE while patient is still in the hospital. Comparted to the old model that could only provide this information long after patient discharge which marginalizes education value of the specific cases.

Our analysis also indicated opportunities for improvement in care. In a couple of cases, thrombosis of superficial veins was treated as DVT while they should not have been. This also offers an opportunity for improved education of medical staff.

Another example for usage of the model involves studying a policy change specifically at the main campus of Henry Ford Hospital. There is a recommendation to order compression stockings for every bed to reduce the time that takes for delivering them to the patients. It is suggested that the unavailability of these stockings is a contributing factor in developing DVT in the main campus. At this location, the rate of DVT is higher than the other three HFHS hospitals which have these stockings available at every bedside. Without having this model, it would be almost impossible to carry out this research study. It is the timeliness, accuracy, and comprehensiveness of this model that can enable such analysis.

CHAPTER 3 VTE RISK ASSESSMENT - IMPLEMENTATION IN EHR

This chapter describes selection of a well-known VTE risk assessment model and implementing it in the EHR to assess patients for risk of developing a VTE in real-time. The contribution in this chapter is the process to translate and replace factors used in a manual risk assessment model to information present in EHR, and presentation of retrospective data analysis that shows the effectiveness of the real-time transformed model.

Background and its importance

As mentioned before, VTE is a serious problem and in the past century, physicians and researchers have tried to create new ways to treat them. Heparin was discovered and introduced in 1916 by Jay McLean and William Henry Howell and then produced in a way to be safely used in treating VTEs in 1936 by Connaught Medical Research Laboratories until today. Heparin and related drugs have enables tremendous improvements in how VTEs are treated and eliminated.

Nevertheless, VTE is still deadly today. It is still costly for both patients and hospitals to treat, and can leave patients with lifetime disabilities and repercussions. Therefore, being proactive is key and any risk assessment model must have a low type I error, false negative rate.

Although pharmacological prophylaxis has proven to be effective, it significantly increases the risk of bleeding for hospitalized patients, especially when the central nervous system is engaged, like in stroke patients[2, 13]. Therefore, it is important for risk assessment models to have a low type II error as well.

In summary, putting patients at risk of internal bleeding should be avoided, but it is generally preferred to the other choice of putting patients at risk of VTE. Therefore, VTE risk assessment models must give priority to a lower type I error rather than a type II error. It is much better to put a few more patients on pharmacological prophylaxis rather than missing the same number of patients who are at risk of getting a VTE.

In the past few decades, there has been an incredible amount of research on causes of thrombosis and identifying the factors that increase the risk of occurrence. It was only in the last 10-15 years that researchers started to advocate individualized patient risk assessment to dive deeper into identifying VTE risk in surgical patients[14-17]. The results looked promising and thus, medical treatment shifted towards individual VTE risk assessment. For example, England made it mandatory in June 2010 to assess individual patients for VTE risk and created a database for hospitals to capture patients' VTE risk assessment data[7].

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[7] https://www.england.nhs.uk

It had been believed that the same VTE risk factors were associated with coronary artery disease risk factors. However in the past decade, analysis of large registries of PE patients (ICOPER: International Cooperative Pulmonary Embolism Registry) and DVT/PE patients (RIETE: Registro Informatizado de la Enfermedad Trombo-Embolica venosa) has shown that the factors are actually quite different[18]. Recent published works have tried to identify these specific risks.

Currently, it is believed that there are three main underlying reasons that cause venous thromboembolism. These are stasis of the blood flow, damage to the vascular endothelial cells, and hypercoagulability. It can be argued that any problem that can cause any of the previously mentioned reasons can in turn increase the risk of developing thrombosis. At the same time, these problems can be temporary, non-modifiable or modifiable[18]. Based on this perspective, the major agreed upon risk factors are summarized in the below table[19, 20]:

Table 3 - Venous Thromboembolism Risk Factors

	Moderate Risk Factors	**Weak Risk Factors**
Modifiable Factors	▪ Oral contraceptive pills	▪ Obesity ▪ Varicose veins ▪ Smoking
Non-Modifiable Factors	▪ Chronic heart failure ▪ Thrombophilia ▪ Prior history of VTE ▪ Respiratory failure ▪ Stroke	▪ Advanced age
Temporary Factors	▪ Cancer ▪ Chemotherapy ▪ Hormone replacement therapy ▪ Pregnancy - Postpartum	▪ Pregnancy - Prepartum ▪ Laparoscopic surgery ▪ Central Venous Catheters

Based on this summary, risk factors are separated into three different groups i.e. modifiable, non-modifiable and temporary based on the nature of the factor. Some factors such as age or thrombophilia are not changeable and once a patient acquires them, they will always have them. Some factors on the other hand are modifiable like smoking or obesity. These factors can be modified by patient education and self-care. The last group are the temporary factors. Factors like cancer or pregnancy must take their due time to be resolved, and generally are out of the hands of the patient to modify.

Caprini Risk Assessment Model

A number of risk assessment models have been published in attempt to stratify patients based on their risk for venous thromboembolism. The most widely used of

one was developed by Caprini, Cohen and Kucher in 2005 based on a combination

of clinical experiments and published data [21-25].

The "Caprini Risk Assessment Model" includes a list of temporary factors such as

specific procedures or illnesses, and non-modifiable factors such as genetic and

clinical characteristics, with assigned relative risk scores to each factor[22, 23].

Then individual risk scores are summed to create a single cumulative score. This

cumulative score is used to assign risk levels to individual patients. This helps

determines the type, intensity and duration of medical prophylaxis used for each

patient.

One example of a Caprini risk assessment questionnaire is shown in Figure 8. It

is maintained on the Agency for Healthcare Research and Quality (AHRQ) Website:

Each Risk Factor Represents 1 Point	
❏ Age 41-60 years	❏ Acute myocardial infarction
❏ Swollen legs (current)	❏ Congestive heart failure (<1 month)
❏ Varicose veins	❏ Medical patient currently at bed rest
❏ Obesity (BMI >25)	❏ History of inflammatory bowel disease
❏ Minor surgery planned	❏ History of prior major surgery (<1 month)
❏ Sepsis (<1 month)	❏ Abnormal pulmonary function (COPD)
❏ Serious Lung disease including pneumonia (<1 month)	
❏ Oral contraceptives or hormone replacement therapy	
❏ Pregnancy or postpartum (<1 month)	
❏ History of unexplained stillborn infant, recurrent spontaneous abortion (≥ 3), premature birth with toxemia or growth-restricted infant	
❏ Other risk factors_____	Subtotal:

Each Risk Factor Represents 5 Points	
❏ Stroke (<1 month)	❏ Multiple trauma (<1 month)
❏ Elective major lower extremity arthroplasty	
❏ Hip, pelvis or leg fracture (<1 month)	Subtotal:
❏ Acute spinal cord injury (paralysis) (<1 month)	

Each Risk Factor Represents 2 Points	
❏ Age 61-74 years	❏ Central venous access
❏ Arthroscopic surgery	❏ Major surgery (>45 minutes)
❏ Malignancy (present or previous)	
❏ Laparoscopic surgery (>45 minutes)	Subtotal:
❏ Patient confined to bed (>72 hours)	
❏ Immobilizing plaster cast (<1 month)	

Each Risk Factor Represents 3 Points	
❏ Age 75 years or older	❏ **Family History of thrombosis***
❏ History of DVT/PE	❏ Positive Prothrombin 20210A
❏ Positive Factor V Leiden	❏ Positive Lupus anticoagulant
❏ Elevated serum homocysteine	
❏ Heparin-induced thrombocytopenia (HIT) (Do not use heparin or any low molecular weight heparin)	
❏ Elevated anticardiolipin antibodies	
❏ Other congenital or acquired thrombophilia	Subtotal:
If yes: Type_____	
* most frequently missed risk factor	

TOTAL RISK FACTOR SCORE: [ ]

Figure 8 - Caprini VTE Risk Assessment - Sample Form [8]

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[8] Agency for Healthcare Research and Quality (AHRQ) Website at https://www.ahrq.gov

Table 4 shows how the total risk score is used to determine prophylaxis regimen in a patient 18 or over who has no condition such as active bleeding that prevent receiving medical prophylaxis. Based on this table, while Caprini score of zero or one indicates low risk for getting a blood clot, ordering anticoagulation is not necessary. On the other hand, as the Caprini score elevates, more potent anticoagulations with higher concentrations are suggested to be ordered.

Table 4 - Caprini Risk Score levels and Recommendations – Sample Table

Total Risk Factor Score	Incidence of DVT	Risk Level	Prophylaxis Regimen
0-1	<10%	Low	No specific measures, Early ambulation
2	10-20%	Moderate	ES. IPC, LDUH or LMWH
3	20-40%	High	IPC, LDUH or LMWH
4	40-60% (1-5% Mortality)	Highest	Pharmacological; LDUH, LMWH, warfarin or Fxa inhibitor alone or in combination with ES or IPC

ES/GCS= elastic stockings/graduated compression stockings; IPC= Intermittent pneumatic compressions;
LDUH= low-dose unfractionated heparin; LMWH= low molecular weight heparin

Although the effectiveness of the Caprini risk assessment has been validated for several different groups of patients[15], there has been criticism around its use. First, it is found to be cumbersome to use, for it requires manual chart reviews and patient examination thus, the model needs to be validated even more for implementation in EHR[2, 26]. Second, the intercorrelation of individual risk factors

is not factored into the model, Thirdly, the model puts most of the hospitalized patients at the high-risk group which increases the risk of administrating unnecessary prophylaxis and putting them at risk of bleeding. For example, any patient above age 60 and obese is automatically scored in the high-risk group and should receive prophylaxis. With Henry Ford Health System's patient population, this model would place almost 95% of the medical patients in the high-risk groups.

The Caprini risk assessment model was not selected to be implemented in Henry Ford's EHR primarily because it requires manual intervention and has a large type II error. In addition, the Caprini risk assessment model was designed based on surgical patients; the aim of this research was to develop a real-time risk assessment model for mainly medical patients.

Padua Risk Assessment Model

In 2010, Barber et al published a prospective study of a cohort of 1,180 patients admitted to a department of internal medicine that were classified at a low or high risk for VTE over a two year period [27]. Cohort patients were followed up on for up to 90 days to check for any occurrences of VTE. The main aim of the study was to see if compliance to VTE prophylaxis in high and low risk patients made a difference in getting a VTE in either of the patient groups. In this study, 39.7% of the patients were marked as high-risk patients. Patients in this group were five

times more at risk of getting a VTE if they did not receive prophylaxis compared to patients who received prophylaxis (11% vs. 2.2%). VTE was also reported in two cases of low-risk patients which accounted for 0.3% of entire low-risk patient population. Bleeding was also documented in three high-risk patients which translated to 1.6% of the patient population.

The proposed model was named "Padua Prediction Score" after the University of Padua in Italy since all patients were selected from the Second Division of Internal Medicine of the university's hospital. As authors put it, "the model itself was empirically generated by adding a few more variables to the Kucher's model" [25] and adjusting scores associated with each factor. Like the Caprini model, individual scores from each factor are added up to create a single total Padua Prediction Score. Any patient with a score of four or higher is considered at high risk for getting a VTE.

Factors included in Padua are summarized in the below table, along with each score assigned to each facto. For example, five features are each assigned scores of 3. This alone would not warrant prophylaxis but adding any other feature such as obesity or age over 70 would make the score 4 or higher.

Table 5 - Padua Prediction Score Factors and Scores

Baseline Feature	Score
Active Cancer	3
Previous Venous Thromboembolism(VTE)	3
Reduced Mobility	3
Already known thrombophilic condition	3
Recent (≤1 month trauma and/or surgery)	2
Elderly Age (≥70 years)	1
Heart and/or respiratory failure	1
Acute Myocardial Infarction (MI) and/or Ischemic Stroke	1
Acute infection and/or rheumatologic disorder	1
Obesity (BMI ≥30)	1
Ongoing hormonal treatment	1

Padua Prediction Score in Real-Time and Challenges

The Padua risk assessment tool is designed for manual chart reviews and/or a patient examinationOur challenge was to find pieces of information from the EHR that can be used either directly or as a surrogate to replicate factors used in Padua. We then needed to show that the modified model is effective. Below is the list of Padua factors along with the challenges of translating each factor:

Active Cancer: In the Padua paper, Active Cancer is defined as "Patients with local or distant metastases and/or in whom chemotherapy or radiotherapy had been performed in the previous 6 months."[27]

Active Cancer is one of the most challenging factors to translate in the Padua model. Based on the definition, there are two pieces of information that need to be identified. Patients with local or distant metastases and chemo/radiotherapy. Below is a description of challenges with each piece:

- **Patients with local or distant metastases:** Generally, there are two main ways to find patient conditions like metastases: Laboratory/Imaging results and H&P/Progress notes. In this case, imaging and lab results were not usable since the results are stored as a free text field, and complicated text analysis method would be needed to identify cancer. The same logic applied to H&P and Progress notes because they also required complex text analysis. There were two main problems to implementing text analysis. First, text analysis proved to be very cumbersome and time consuming to setup and optimize. Second, the EHR did not support the functionality to implement such complex methods.

- **Chemotherapy or radiotherapy had been performed in the previous 6 months:** Chemotherapy and radiotherapy are usually done in outpatient centers. An initial analysis identified the following challenges to use this as a surrogate indicator of active cancer. The chemotherapy medication and concentration combination were not than specific enough to pinpoint active

cancer. There were also other reasons for receiving the medications or radiotherapy. Therefore, the clinical staff advised the project not to use these triggers to find active cancer patients.

The only remaining alternative was to use information from problem list charting in the EHR and to develop a meaningful logic that would yield reasonably meaningful and useful results. The first logic used was to use open problem list items from patients' records. Initially, to identify cancer among other items within the problem list, a list of ICD9[9] codes were used. This initial list is available in the appendix.

ICD9 was originally a three to five-digit code that was designed mainly for billing and tracking to specify patient diagnosis and problems. The model then was extended in two different versions in the US (ICPM and ICD-9-CM) to include procedure and diagnostic tests. In 1979, the US started requiring ICD-9-CM to pay for Medicaid and Medicare claims. The structure of the ICD9 code is depicted in the below figure.

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[9] 9th revision of the International Statistical Classification of Diseases and Related Health Problems (ICD), a medical classification list by the World Health Organization (WHO)
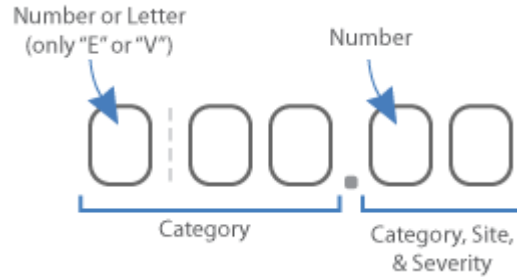
Figure 9 - Structure of ICD9[10]

Initial chart review for a group of 40 patients showed that none of the cancer cases were missed. However, using problem lists triggered five cases with a history of cancer but not active cancer. This revealed a general problem with using problem lists. Interviewing a few physicians and reviewing charts of patients clarified that providers were not as accurate in documenting resolution of patients' problems compared to noting a new problem. As explained in the beginning of this chapter, although this causes data to inflate number of patients deemed to have active cancer, it does not miss active cancer patients.

After working with the data for a few months and going through more sets of chart reviews, the final list of ICD9 was limited to any ICD9 number starting with 140 through 209. This list proved to capture less false positives for the Padua risk assessment tool while keeping its sensitivity to finding active cancer in the problem list. One event that affected the study greatly was the introduction of the tenth

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[10] http://www.icd10codesearch.com/training.php

version of the International Classification of Diseases (ICD10) in Oct 2015. The new global coding system increased the number of codes to more than 14,000 and the new challenge was to adjust criteria for each of the entries using the ICD10 list. The new coding system uses a character followed by two digits that describes the category of diseases, signs and symptoms, abnormal findings, complaints, social circumstances, or external causes of injury or diseases.
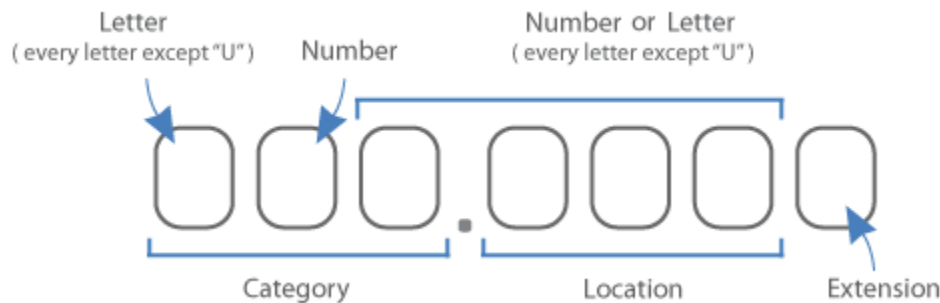
Figure 10 - Structure of ICD10 code[11]

For example, character "S" is used to identify a group of problems containing injury, poisoning and certain other consequences of external causes. The next two letters are then used to identify specific category of problems. In the below example, S42 is used to indicate "Displaced Transverse Fracture." The second half of the code, which is separated from the first three letters using a dot, is used to describe the problem more specifically. For problems and symptoms that do not necessarily need a more specific description, this part is not mandatory.

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[11] http://www.icd10codesearch.com/training.php

In the below example, the first digits i.e. 3, identifies the etiology of a fracture identified as Humerus. The second digit specifies the location i.e. 2 for shaft of the Humerus. The third digit specifies the laterality. Here, 1 for right arm. The last character which is "A" shows that this case is an initial encounter for this specific problem.
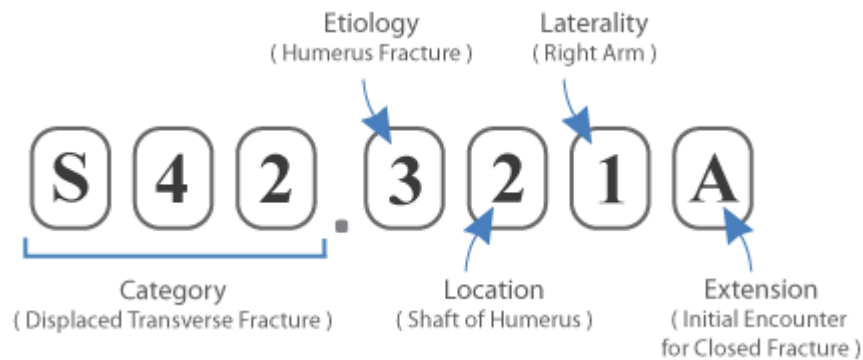
Figure 11 - ICD10 structure explained using an example[12]

For the case of active cancer, ICD10 codes started with letter "C". The full list is available in the appendix.

Previous Venous Thromboembolism(VTE): In the Padua risk score, previous VTE is one of the factors with three points. This factor is explained by Barber et al. as "Previous VTE (with exclusion of superficial vein thrombosis)" and this is exactly the criteria used in chapter one for VTE harm measurement. The major difference is all

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[12] http://www.icd10codesearch.com/training.php

problem list including active encounter and previous encounters as well as medical history of the patient must be considered.

One of the early challenges was to identify a list of ICD9 codes that indicate presence of DVT or PE. Before October 2015 and when only ICD9s were available, finding a clear distinction between deep vein thrombosis and superficial vein thrombosis was impossible. In some instances, shared ICD9 codes had been defined to identify both deep as well as superficial vein thrombosis. Hence, an initial set of ICD9 codes were selected by sifting through the list of ICD9 codes with a provider. The list then optimized through a few iterations of selection and chart reviews until an acceptable final list was obtained. This final list of ICD9 codes is attached in the appendix.

The introduction of the ICD10 codes in October 2015 required us again to update the rules for identifying previous VTE. Over a few months' time period and using the same procedure, an initial list of ICD10s was transformed into a final list of ICD10 codes to determine previous VTE. In each step, a set of chart reviews should have been performed by physicians to determine if a (set of) ICD10 code should be included/excluded. Then false positive and false negative rates were reviewed. However, the major advantage of the ICD10 is its specificity of the coding system, which helps determine a meaningful clean list of ICD10s representing VTEs.

There are cases in which providers did not select a specific entry from the problem list and simply wrote the VTE instance into the problem list. These cases are not considered in the model due to the fact that EHR does not support implementation of text search in the logic.

Reduced Mobility: Reduced mobility was another challenging factor in determining the Padua risk score. It scored three points, making it important to identify it as accurately as possible. In the Padua study, reduced mobility is described as "Bedrest with bathroom privileges (either due to patient's limitations or on physician's order) for at least 3 days." by Barbar et al. [27]. Finding bedrest orders from the EHR has its own challenges. Although bedrest orders are captured within the EHR, they are generally not well-documented and nor tracked very well. In the case study, the end or stoppage of any order in the EHR was not reliably recorded. As a result, and after meetings with different providers, it was decided not to use bedrest orders to determine reduced mobility.

Different alternatives were identified and discussed. Eventually the only reliable candidate, the "Braden Mobility Scale" was used as a surrogate to determine reduced mobility. This scale is one of the components of the Braden tool that was originally created in 1987 by Barbara Braden and Nancy to predict pressure ulcer risk [28]. Below is a summary of different scales of the Braden mobility scale:

1- COMPLETELY IMMOBILE – Does not make even slight changes in body or extremity position without assistance.

2- VERY LIMITED – Makes occasional slight changes in body or extremity position but unable to make frequent or significant changes independently.

3- SLIGHTLY LIMITED – Makes frequent though slight changes in body or extremity position independently.

4- NO LIMITATIONS – Makes major and frequent changes in position without assistance

One of the biggest advantages of Braden Mobility Scale is the availability of data. Per nursing protocols, nurses are required to document this score every four hours, every one hour, and every 30 minutes for patients in general units, intensive care units, and patients with restraints respectively. Not only is this scale well documented, and readily available as an integer data field, it is also reasonably accurate.

However, one major problem with using this scale is the principle that determination of the reduced mobility must be called by the providers while in real time, the scale is determined and documented by nurses. At first, the validity of the criteria was questioned by a few providers. However, , they eventually agreed that

the use of the Braden scale is logical and in in fact the best surrogate alternative available in the EHR.

The challenge following this was to determine the correct level of the Braden Mobility Scale that could determine or imply reduced mobility. A patient with a four was obviously not immobile. The problem was to draw a line to determine the right level within the scale from 1 to 3. A one was probably the most obvious to include in the criteria. Initial data analysis shows that only a small percentage of the patients were given a score of one. At the same time, scale three was extremely general. An initial data analysis showed that most hospitalized patients regardless of condition, faced this level of reduced mobility at some point.

Eventually scale one and two were considered as surrogates to determine reduced mobility for the risk of VTE. Note that the Padua study described the reduced mobility to be somewhat lengthy (three days). However, using one data point seemed acceptable since it reduces the potential chance of missing patients, ultimately reducing the type I error.

Already Known Thrombophilic Condition: Defined as "Carriage of defects of antithrombin, protein C or S, factor V Leiden, G20210A prothrombin mutation, antiphospholipid syndrome"[27].

The description simplifies the determination of thrombophilia, since there are different problems that can cause temporary thrombophilic conditions. The description clearly specifies only congenital and genetically carried conditions.

Like cancer and VTE history, a problem list was used to determine thrombophilia. Initially "ICD9 287.5 Thrombocytopenia, unspecified" was used in the logic. After October 2015 "ICD10 D69.6 Thrombocytopenia, unspecified" was used as the criteria to find thrombophilia.

Recent (within last month) Trauma and/or Surgery: This factor is the only one within the Padua score that gets two points. Unfortunately, there is no specific description of this factor in the Padua study, and the description of "trauma" can have many different definitions. Therefore, defining "trauma" was one of the primary challenges for this factor. Luckily, Epic EHR had an internally predefined set of diagnosis lists that was used to determine and define trauma. By the beginning of 2017, there were more than 1.6 million entries on this list, preventing it from being reported in this document. The major advantage of this set is the fact that the EHR itself (in this case a team in Epic), oversees making sure the list is being maintained and updated. Therefore, there was no need to develop or maintain a list of all trauma diagnosis codes. Many chart reviews with providers proved that the predefined set is performing reasonably well. As a result, the problem list along

with notation date of the problem list entry (which must have happened within 30 days prior to the assessment time) were used as the criteria to determine "recent" trauma.

Catching recent surgery within 30 days was far easier to identify as surgical cases are well documented within the surgical module in the EHR. The major problem with identifying either recent trauma or surgery within 30 days, is the fact that any prior medical condition or surgery is documented in the medical history and surgical history of the patient. However, neither of them have specific date fields to capture occurrence date and time. The date and time is rather captured within a text field, and as a result, it is not reliably and correctly identifiable. Therefore, any instance of recent surgery or trauma if served and recorded within another health system is potentially missed using this method. The proposed model would miss these cases.

Elderly age (Greater or equal to 70 years): While the age factor only gets one point within the Padua score, it is the most straightforward factor to identify. Age of the patients at the time of assessment (which is current system time) is considered to determine age and if the patient is 70 years of age or older, they are assigned one point.

Obesity (BMI Greater or equal to 30): Obesity is reasonably straightforward to identify. A patients' BMI is normally calculated at any time using the last measured (known) patient height and weight. In this case, patients who have a BMI of 30 or greater, are assigned one point.

Heart and/or Respiratory Failure: Having a history of either heart or respiratory failure gets one point in the Padua risk tool. Fortunately, like trauma, there is a predefined set of diagnosis codes used to determine them. These sets were utilized in both medical history of patients and their problem lists to determine history of heart or respiratory failure.

Acute Myocardial Infarction (AMI) or Ischemic Stroke: As with heart and respiratory failure, there were predefined sets available for both AMI and ischemic stroke. The same process was followed for this factor and any patient with a history of AMI and/or ischemic stroke was assigned one point.

Acute Infection and/or Rheumatologic Disorder: Based on this factor, any patient with rheumatologic disorder and/or acute infection should get one point in the Padua risk assessment tool. Rheumatologic disorder could be identified using the problem list and medical history of the patient. The final list of ICD9 and ICD10 that was used respectively prior to and after October 2015, is available in appendix.

However, identifying acute infection proved to be much harder than initially thought. Unfortunately, there was no easy way to capture it. One difficulty in finding acute infections was the fact that patients must have the condition at the time of the assessment to receive the additional point. Again, using H&P to capture acute infections was out of the question since it required natural language processing. Problem lists also proved to create a huge number of false positives. To overcome this issue, an algorithm was developed to identify acute infections more accurately. The idea for the algorithm came from the VTE harm measurement that was explained in chapter one. In theory, a patient should have had an acute infection if they had an entry for any type of infection in their problem list and receiving any type of anti-bacterial, anti-viral or anti-fungal treatment. A series of 50 initial chart reviews showed that the algorithm performs reasonably well. While the proposed algorithm enjoyed a sensitivity of 100%, it generated five false positives.

Fortunately, building the proposed algorithm did not require perfection of a long list of ICD9/ICD10s and infection medication treatments. Because Epic EHR also included a predefined set of infection diagnosis codes as well as a list of infection treatment medications.

Ongoing Hormonal Treatment: Ongoing hormonal therapy is another factor in the Padua risk tool that can get up to one point. There were two main reasons that made identification of ongoing hormonal treatment a challenge. First, determining the "ongoing" part of the factor was not possible. Therefore, it was decided to look at patients with any type of hormonal treatment. And second, the EHR did not provide a predefined list of entire hormonal treatment medications, and developing a clean list of medications that can be counted as hormonal treatment was not a trivial task. There were literally thousands of medications that could be counted in the list, and cleaning the list seemed impossible. And with new medications being added by the pharmacy on a regular basis, maintaining the list was impossible.

The only option was to use one of the predefined list of medications in the EHR, which only included a portion of the medications. However, it was maintained by the EHR on a regular basis.

Performing a few chart reviews with the physicians showed using this predefined list can miss a fair amount of true cases of hormonal treatment. Several discussions with physicians did not produce a better alternative to improve the logic and hence, it was decided to use the predefined list in the final design.

Padua Risk Assessment - Implementation

The implementation of the tool in the EHR took about 6 months to complete and perfect. EHR tools for deploying risk assessment tools have limitations and nuances that needed to be investigated. Basically, on each iteration of updating the tool in the EHR, the results had to be compared to the ones from the program to make sure the deployed tool reflected accurate results based on intended designs.

The figure below shows how the tool can be utilized by the providers on their day to day job. There are two ways to show the Padua risk score in the EHR. Either physicians can add the score to their assigned patients' lists, or they can run a report that lists every single patient in the hospital along with the risk scores.

Figure below is a real example of a few patients that were admitted to the ICU at Henry Ford Hospital on a specific date and time. Patient identifiers are covered with black ink to ensure privacy of the patients.

It is worth noting that the Padua score is measured for each patient on the fly, and as soon as anything occurs that could change the score, the records are updated in real time. Scores of four or greater which represent high-risk patients are clearly marked in red to stand out.

One powerful aspect of this tool is that providers can add the risk score side by side with heparin/LMWH and/or anticoagulation medications. In this case, they can

quickly go through their lists of patients and investigate whether a high-risk patient

is receiving prophylaxis, if they have a contraindication to receive one, or if they

must order VTE prophylaxis for the patients. They can also find patients with low

risk of VTE and decide if they need to stop the VTE prophylaxis for them.

Figure 12 - Patient List within EHR showing Padua Risk Score

In the above example, the first patient is clearly at risk of VTE with a Padua score

of eight. And the next two columns indicate that they are not receiving any

anticoagulation. The next step for the providers is to investigate if there is a

contraindication for not receiving anticoagulation. In this example, the patient

clearly has a problem of "Acute Upper Gastrointestinal Bleeding" as their primary

problem, and that is one major reason not to receive blood thinners.

This tool also provides another functionality. The fifth patient on the list shows a very high Padua risk score of 11. The patient is not receiving any anticoagulation, and the main problem on the list does not provide any insight as to whether there are contraindications for not receiving prophylaxis. In cases like these, providers should open patients' charts and review their records. This can take some time.

The drawer tool within the Padua tool makes this task much easier. There is a button on the bottom of the providers' list that provides a summary of patient records. This helps providers quickly review a long list of patients in a short amount of time. In this example, the provider can quickly identify that the patient has active cancer, reduced mobility and a history of congenital heart failure.

Figure 13 - Drawer Tool Showing Details within Padua Tool in EHR

Padua Risk Assessment – Accuracy and Effectiveness

The below table summarizes the number and percent of patients identified as high risk for developing VTE. The analysis is done separately for medical patients from specific medical units within Henry Ford Hospital, as well for all patients within the health system.

The data shows that Padua risk assessment only identifies 25% of the medical patients as high risk for developing a VTE (23% for all patients). This shows higher levels of sensitivity compared to the Caprini model. Initial estimates for the portion of patients considered to be high risk with the Caprini model were above 90%. Our new scale eliminated unnecessary prophylaxing of roughly 64% of the patients, which in turn reduces their risk of developing internal bleeding.

Table 6 - Ratio of High Risk Patients using Padua Risk Score

Patient Group	Low Risk VTE (Population and %)	High Risk VTE (Population and %)	Total
Medical Patients within specific units within HFH	10,685 (63.5%)	6,132 (36.5%)	16,817
All Patients within system	165,074(66.2%)	84,248(33.8%)	249,322

Table below shows how the Padua risk score performs as a predictive of developing VTE. To sum up, the rate of developing a VTE among low risk medical patients was only 0.34%, compared to 2.33% for high risk medical patients. Looking at all patients within the health system the same ratio is 0.28% compared to 2.33%.

Table 7 - VTE Harm Rate in High Risk and Low Risk Patients

Patient Group	Low Risk VTE (Number and VTE%)	High Risk VTE (Number and VTE%)	Total
Medical Patients within specific units within HFH	12,605 (0.34%)	4,212 (2.33%)	16,817(1.06%)
All Patients within system	190,986(0.28%)	58,336(2.33%)	249,322(0.98%)

Performing a t-test for comparison of proportions in the two groups using alpha= 0.05 concludes that there is significant difference between the VTE harm rate in each group.

	Sample 1	Sample 2	Difference
Sample proportion	0.0034	0.0233	0.0199
95% CI (asymptotic)	0.0025 - 0.0043	0.0195 - 0.0271	0.0172 - 0.0226
z-value	12.3		
P-value	0		
Interpretation	Statistically significant, reject null hypothesis that sample proportions are equal		
n by pi	n * pi >5, test ok		

Figure 14 - t-Test output for difference of VTE rates
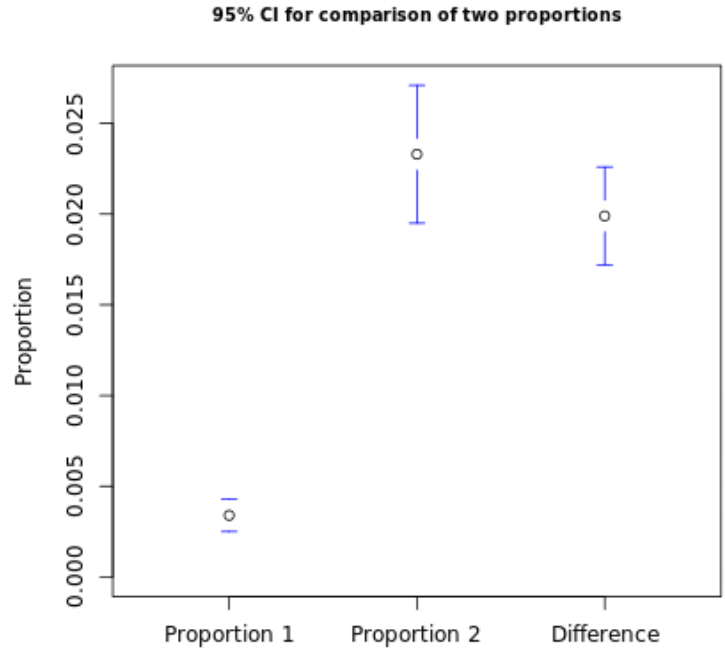
Figure 15 - Confidence Intervals for comparison of VTE Harm Rates

This Padua EHR implementation proved to be very useful. However, this chapter identified and discussed its shortcomings. The next chapters explain an alternative risk assessment model improves the performance of the model. Chapter 5 summarizes the outcome of the Padua model and the contributions it made to hospital quality and patient safety.

CHAPTER 4 ALTERNATIVE TO PADUA – IMPROVE

In this chapter, another well-known VTE risk assessment model - "IMPROVE"- will be discussed. This will include a review of the validation of the performance of this model will be reviewed. Finally, a comparison between IMPROVE and the implemented Padua risk assessment model in the EHR will be provided.

Why IMPROVE?

In the previous chapters, the Padua risk assessment model and its advantages were discussed; however, there are some challenges when it comes to the implementation of this model which motivated the review and introduction of another VTE risk assessment model in this chapter. The implementation challenges of the Padua model are as follows:

- To implement the Padua model, some trade-offs were needed to be made (such as using the Braden score as a surrogate indicator for determining immobility) which have been discussed in the previous chapters. These trade-offs could potentially have an adverse effect on the performance of the Padua model in terms of its sensitivity and specificity. Furthermore, a few physicians were reluctant to use the model due to these trade-offs and the complex explanations that come with them.

- In general, the Padua is a complicated model, and not every physician can quite understand the relationships in the model. They also tend to question the underlying structure of the implemented model. Explaining the complex implementation concepts seem to overwhelm and sometimes confuse some physicians.

- There is no consensus between experts with regards to the accuracy and performance of this model.

- Design and implementation of the Padua model is complicated due to the number of parameters used. It is, therefore, difficult to timely and accurately trace the important changes in these parameters over time. This can make the maintenance of the Padua model quite burdensome, time consuming, and in some ways, impossible. Not only can this negatively affect the performance of the model, but also the physicians' perception of it.

IMPROVE Risk Assessment Model

Spyropoulos, MD et al. introduced the IMPROVE risk assessment model in their paper titled "Predictive and Associative Models to Identify Hospitalized Medical patients at Risk for VTE" in 2011 [29]. The model was derived through multiple regression analysis of more than fifteen thousand hospital admissions that were

observed for a period of three months after discharge. All data was obtained from the observational International Medical Prevention Registry on Venous Thromboembolism (IMPROVE) study.

Spyropoulos, MD et al. concluded their study with a weighted VTE risk score using only four clinical factors. The table below summarizes these factors along with the reported significances and points assigned to each factor in the model[29]:

Table 8 - Adjusted Predictive Model for VTE – Improve Model[29]

VTE Risk Factor	HR (95% CI)	X^2	P Value	Points
Previous VTE	5.0 (3.3-7.8)	53	<0.001	3
Known Thrombophilia*	5.2 (1.3-21.5)	5.2	0.02	3
Cancer	2.0 (1.3-3.1)	11	0.001	1
Age > 60 y	1.8 (1.2-2.7)	8.5	0.004	1

* Antithrombin, protein C, protein S, factor V Leiden, prothrombin gene mutation, or antiphospholipid syndrome[29].

In this model, the total risk score is calculated by adding all the points from each factor, and a total score of two or more is considered as a high risk for VTE.

Validation of the IMPROVE Model– Literature Review

There have been a few studies that aimed to validate the IMPROVE risk assessment model. For instance, assessing the validity of the model was the main subject of a study published in Journal of the American Heart Association (JAHA) by Rosenberg et al. in 2014[30]. This study reported an overall VTE rate of 0.7% for a population of 19,217 patients who matched the criteria of the IMPROVE study.

They observed a 0.42% (95% CI 0.31 to 0.53) rate for low risk patients, and 1.29% (95% CI 1.01 to 1.57) rate for high risk patients as identified by IMPROVE risk assessment model.

The paper titled "External validation of a risk assessment model for venous thromboembolism in the hospitalized acutely-ill medical patient (VTE-VALOURR)" published by Mahan et al.[31] also sought validation of the IMPROVE model. Using a cohort of 41,486 hospitalizations, VTE rates of 0.20% (95% CI 0.18 to 0.22), 1.04% (95% CI 0.88 to 1.25) and 4.15% (95% CI 2.79 to 8.12) were reported for low-risk, medium-risk and high-risk VTE patients respectively. In this study, 68.6%, 24.8% and 6.5% of the patient population were classified by the IMPROVE model as low-risk, medium-risk and high-risk patients. Area Under Curve(AUC) was also found to be 0.7731 for IMPROVE risk assessment model.

Lew et al. (2017) published the paper "Extended-duration versus short-duration pharmacological thromboprophylaxis in acutely ill hospitalized medical patients: a systematic review and meta-analysis of randomized controlled trials"[32]. They concluded that extended duration thromboprophylaxis administration for high risk VTE patients as identified by IMPROVE model reduces the overall risk of symptomatic DVT and symptomatic non-fatal PE with increase in risk for major non-fatal bleeding [32].

IMPROVE Risk Assessment Model – EHR Implementation Analysis

Implementation of any new model in the EHR must undergo feasibility studies and IMPROVE was no exception. However, performing the feasibility studies for IMPROVE was straightforward. As the IMPROVE model consists of only four main factors (i.e. previous VTE, thrombophilia, active cancer and age older than 60 years) which are among factors that were used in developing the PADUA model. Therefore, all four factors could be copied from the existing build to create the new IMPROVE model.

Our initial analysis was designed to see how IMPROVE performed against the currently developed PADUA model. First, there was a determination of the percentage of medical patients that are considered high risk for VTE. These are the patients that will get medical VTE prophylaxis. Initially four specific units were considered to do this analysis. These units are "HFH B1 Internal Medicine,", "HFH B4 Internal Medicine," "HFH F1 Hospitalist Medicine," and "HFH F4 Internal Medicine". These units were selected from Henry Ford Hospital because they are serving similar medical patients who do not have major complications that could potentially affect the performance of either models.

Among 16,817 patients who visited any of these four specific units since January 2014 until April 2017, PADUA identified 6,132 (36.46%: 95% CI 35.45% to 37.47%)

as high risk and 10,685 (63.54%: 95% CI 62.77% to 64.31%) as low-risk VTE patients.

For the same group of patients IMPROVE identified 4,212 (25.05%: 95% CI 23.95%

to 26.15%) and 12,605(74.95%: 95% CI 74.32% to 75.58%) respectively as high-risk

and low-risk VTE patients. Table below summarizes this comparison.

Table 9 - Patient Population: PADUA vs. IMPROVE

Assessment Model	Low-Risk VTE Patient Count (%)	High-Risk VTE Patient Count (%)
Implemented PADUA	10,685 (63.54%)	6,132 (36.46%)
IMPROVE	12,605 (74.95%)	4,212 (25.05%)

Figure 16 and Figure 17 show the results of t-tests used to check the statistical

significance of differences between proportions using two methods. These tests

conclude that IMPROVE significantly marks less patients as high-risk compared to

PADUA. Conversely, IMPROVE identifies more patients as low-risk compared to

PADUA. To put this into perspective, PADUA on average puts almost 11 more

patients out of any 100 patients on medical prophylaxis compared to IMPROVE. As

discussed, in addition to direct costs of medical prophylaxis for 11 patients, this

means 11 more patients at risk of internal bleeding.

	Sample 1	Sample 2	Difference
Sample proportion	0.3646	0.2505	0.1141
95% CI (asymptotic)	0.3545 - 0.3747	0.2395 - 0.2615	0.0988 - 0.1294
z-value	12.2		
P-value	0		
Interpretation	Statistically significant, reject null hypothesis that sample proportions are equal		
n by pi	n * pi >5, test ok		

Figure 16 - High-Risk VTE Patient Proportion Test: PADUA vs. IMPROVE

	Sample 1	Sample 2	Difference
Sample proportion	0.6354	0.7495	0.1141
95% CI (asymptotic)	0.6277 - 0.6431	0.7432 - 0.7558	0.1042 - 0.124
z-value	18.9		
P-value	0		
Interpretation	Statistically significant, reject null hypothesis that sample proportions are equal		
n by pi	n * pi >5, test ok		

Figure 17 - Low-Risk VTE Patient Proportion Test: PADUA vs. IMPROVE

The study next compared how these models perform in determining risk of getting a VTE. Analyzing the same group of patients, 0.34% (95% CI: 0.25% to 0.43%) of them were identified as low-risk for VTE by PADUA acquired a VTE, while 2.33% (95% CI: 2.01% to 2.65%) of high-risk VTE patients acquired a VTE. IMPROVE outperformed PADUA. Only 0.28% (95% CI: 0.2% to 0.36%) of low-risk patients

experienced a VTE as compared to 3.42% (95% CI: 2.96% to 3.88%) for patients

identified as high-risk VTE. This comparison is summarized in table below.

Table 10 - PADUA vs. IMPROVE: VTE Rate Comparison

Assessment Model	Low-Risk: VTE Rate (%)	High-Risk: VTE Rate (%)
Implemented PADUA	0.34%	2.33%
IMPROVE	0.28%	3.42%

The below figures show t-test results for comparing VTE rates in each group. To

summarize, patients who were identified by IMRPOVE as high-risk were

significantly more likely to experience a VTE than patients who were identified by

PADUA as high-risk. In low-risk patients, although the results were not statistically

significant, IMPROVE identified low-risk patients had a lower VTE rate.

These analyses show that IMPROVE can significantly reduce the cost and need

for prophylaxis, thereby reducing the risk of bleeding. It also was significantly more

sensitive in identifying patients who are truly at risk of VTE.

	Sample 1	Sample 2	Difference
Sample proportion	0.0034	0.0028	6e-04
95% CI (asymptotic)	0.0025 - 0.0043	0.002 - 0.0036	-6e-04 - 0.0018
z-value	0.8		
P-value	0.205		
Interpretation	Not significant, accept null hypothesis that sample proportions are equal		
n by pi	n * pi >5, test ok		

Figure 18 - VTE Rate in Low-Risk Patients t-test: PADUA vs. IMPROVE

	Sample 1	Sample 2	Difference
Sample proportion	0.0233	0.0342	0.0109
95% CI (asymptotic)	0.0201 - 0.0265	0.0296 - 0.0388	0.0055 - 0.0163
z-value	3.3		
P-value	0.0005		
Interpretation	Statistically significant, reject null hypothesis that sample proportions are equal		
n by pi	n * pi >5, test ok		

Figure 19 - VTE Rate in High-Risk Patients t-test: PADUA vs. IMPROVE

The above analysis was first performed for a group of similar patients who did not have complexities that could affect the model. But what if the same analysis is done for all patients including GI bleed, stroke, surgical patients, and so on? The same analysis was performed using a dataset of nearly 250,000 hospital admissions across four different hospitals since January 2014.

Data analysis on the new more diverse and larger group of patients virtually showed the same results. Out of 249,322 patients 165,074 (66.21%: 95% CI 66.02%

to 66.40%) and 84,248 (33.79%: 95% CI 33.52% to 34.06%) were identified as low-risk and high-risk VTE patients using implemented PADUA model. The corresponding statistics for IMPROVE model are respectively 190,986 (76.6%: 95% CI 76.44% to 76.76%) and 58,336 (23.40%: 95% CI 23.11% to 23.69%) for low-risk and hi-risk patients.

Below is a summary of these results as well as statistical analysis for difference between proportions. These results confirm previous analysis and show that IMPROVE will, on average, result in 10% fewer high-risk patients compared with PADUA. In this study, this is a total of almost 26,000 fewer patients needing prophylaxis.

Table 11 - Patient Population: PADUA vs. IMPROVE

Assessment Model	Low-Risk VTE Patient Count (%)	High-Risk VTE Patient Count (%)
Implemented PADUA	165,074 (66.21%)	84,248 (33.79%)
IMPROVE	190,986 (76.60%)	58,336 (23.40%)

	Sample 1	Sample 2	Difference
Sample proportion	0.6621	0.766	0.1039
95% CI (asymptotic)	0.6602 - 0.664	0.7644 - 0.7676	0.1014 - 0.1064
z-value	68.7		
P-value	0		
Interpretation	Statistically significant, reject null hypothesis that sample proportions are equal		
n by pi	n * pi >5, test ok		

Figure 20 - Low-Risk VTE Patient Proportion Test: PADUA vs. IMPROVE

	Sample 1	Sample 2	Difference
Sample proportion	0.3379	0.234	0.1039
95% CI (asymptotic)	0.3352 - 0.3406	0.2311 - 0.2369	0.0999 - 0.1079
z-value	42.3		
P-value	0		
Interpretation	Statistically significant, reject null hypothesis that sample proportions are equal		
n by pi	n * pi >5, test ok		

Figure 21 - High-Risk VTE Patient Proportion Test: PADUA vs. IMPROVE

In terms of VTE rates, IMPROVE still outperforms PADUA in sensitivity for determining high-risk patients. VTE rates for low-risk patients are virtually the same with 0.28% for PADUA compared with 0.29% for IMPROVE. On the other hand, IMPROVE had a rate of 3.24% VTE for its high-risk patients compared with 2.33%

for high-risk patients identified by PADUA. These rates along with statistical analysis comparing two groups together are summarized below.

Table 12 - PADUA vs. IMPROVE: VTE Rate Comparison

Assessment Model	Low-Risk: VTE Rate (%)	High-Risk: VTE Rate (%)
Implemented PADUA	0.28%	2.33%
IMPROVE	0.29%	3.24%

	Sample 1	Sample 2	Difference
Sample proportion	0.0233	0.0324	0.0091
95% CI (asymptotic)	0.0224 - 0.0242	0.0312 - 0.0336	0.0077 - 0.0105
z-value	10.4		
P-value	0		
Interpretation	Statistically significant, reject null hypothesis that sample proportions are equal		
n by pi	n * pi >5, test ok		

Figure 22 - VTE Rate in High-Risk Patients t-test: PADUA vs. IMPROVE

	Sample 1	Sample 2	Difference
Sample proportion	0.0028	0.0029	9.99999999999998e-05
95% CI (asymptotic)	0.0026 - 0.003	0.0027 - 0.0031	-2e-04 - 4e-04
z-value	0.6		
P-value	0.2885		
Interpretation	Not significant, accept null hypothesis that sample proportions are equal		
n by pi	n * pi >5, test ok		

Figure 23 - VTE Rate in Low-Risk Patients t-test: PADUA vs. IMPROVE

IMPROVE Implementation Assessment – Enhancement

The second step in designing the IMPROVE model for implementation in the EHR was to specify factors that could be better identified by extracting information from the EHR. Age is a factor that could not be improved. For the other three factors, active cancer was the most challenging one. These challenges were explained in chapter three. To summarize, active cancer is determined by considering open entries in problem list that have any of the identified cancer ICD10 codes.

A cancer code on the problem list does not necessarily mean the cancer is active. It is considered active cancer if the cancer problem was added or updated within the current hospital encounter. Thus, if a patient is admitted to the hospital and the admitting physician does not document the active cancer in the problem list, this cancer is not included in the risk factor.

The new improved model hereafter is called "Enhanced IMPROVE". Below is a summary of how the new design lines up against the other two models using the controlled group patients and bigger patient group.

Table 13 - Low-Risk and High-Risk Patient Population - Enhanced IMPROVE

Sample	Assessment Model	Low-Risk VTE Patient Count (%)	High-Risk VTE Patient Count (%)
Four Units	Implemented PADUA	10,685 (63.54%)	6,132 (36.46%)
	IMPROVE	12,605 (74.95%)	4,212 (25.05%)
	Enhanced IMPROVE	13,394 (79.65%)	3,423 (20.33%)
All Four Hospitals	Implemented PADUA	165,074 (66.21%)	84,248 (33.79%)
	IMPROVE	190,986 (76.60%)	58,336 (23.40%)
	Enhanced IMPROVE	203,889 (81.78%)	45,433 (18.22%)

Table 14 - VTE Rate - Enhanced IMPROVE vs. PADUA vs. IMPROVE

Sample	Assessment Model	Low-Risk VTE Patient Count (%)	High-Risk VTE Patient Count (%)
Four Units	Implemented PADUA	0.34%	2.33%
	IMPROVE	0.28%	3.42%
	Enhanced IMPROVE	0.28%	4.15%
All Four Hospitals	Implemented PADUA	0.28%	2.33%
	IMPROVE	0.29%	3.24%
	Enhanced IMPROVE	0.29%	4.06%

Both of the above tables show that Enhanced IMPROVE outperforms IMPROVE and PADUA in terms of sensitivity and specificity. It reduced the number of patients classified as high risk and those patients had higher rates of VTE. The increase in low risk patients did not affect the rate of VTE within this group as compared to IMPROVE.

The below graphs show statistical analysis performed comparing the Enhanced IMPROVE and IMPROVE on these measures.

	Sample 1	Sample 2	Difference
Sample proportion	0.2505	0.2035	0.047
95% CI (asymptotic)	0.2395 - 0.2615	0.1922 - 0.2148	0.0311 - 0.0629
z-value	4.9		
P-value	<0.0001		
Interpretation	Statistically significant, reject null hypothesis that sample proportions are equal		
n by pi	n * pi >5, test ok		

Figure 24 - High-Risk Patient Population: IMPROVE vs Enhanced IMPROVE

	Sample 1	Sample 2	Difference
Sample proportion	0.7495	0.7965	0.0469999999999999
95% CI (asymptotic)	0.7432 - 0.7558	0.7908 - 0.8022	0.0385 - 0.0555
z-value	9.1		
P-value	0		
Interpretation	Statistically significant, reject null hypothesis that sample proportions are equal		
n by pi	n * pi >5, test ok		

Figure 25 - Low-Risk Patient Population: IMPROVE vs Enhanced IMPROVE

	Sample 1	Sample 2	Difference
Sample proportion	0.0324	0.0406	0.0082
95% CI (asymptotic)	0.0312 - 0.0336	0.0391 - 0.0421	0.0063 - 0.0101
z-value	7		
P-value	<0.0001		
Interpretation	Statistically significant, reject null hypothesis that sample proportions are equal		
n by pi	n * pi >5, test ok		

Figure 26 - VTE Rate in High-Risk Patients: IMPROVE vs. Enhanced IMPROVE

Enhanced IMPROVE on average classifies 5% fewer high-risk patients compared to IMPROVE without increasing the aggregate risk of VTE for low-risk patients. The rate of VTE among high-risk patients identified by improved IMRPOVE is also significantly higher than IMPROVE with 4.06% which is the equivalent of one out of every twenty-five patients.

The risk of VTE for patient who identified as high-risk by IMPROVE and low-risk by enhanced improve is calculated to be 0.32% for all patients in all four hospitals. This is not statistically significantly higher than of 0.32% for Enhanced Improve (using alpha=0.05).

Based on this analysis, "Enhanced IMPROVE" was selected and scheduled to be implemented in late 2017- early 2018 into the EHR. It will then be used in all four hospitals to determine VTE risk for patients and hence the VTE prophylaxis regimen.

The next chapter will explain outcomes of the developed PADUA model, byproducts of this study, including data marts and dashboards, a few quality projects and their outcomes that were performed using this study, and finally a summary of a few publications that was made possible because of this study.

CHAPTER 5 CONCLUSION: STUDY CONTRIBUTIONS AND RESULTS

This chapter discusses how this research contributes to improvements in monitoring hospital acquired VTEs, an important hospital quality measure. Furthermore, the discussion includes how the research leads to facilitating better VTE risk management, and saving lives through targeted education of patients, nurses and residents. The chapter then follows with discussions around how the developed models have improved quality of patients' lives and financial savings for the hospital.

New Way of Hospital Acquired VTE Measurement

As discussed before, the traditional VTE measurement method uses billing data. The drawbacks of this method included first, the lag between the time a VTE episode occurs and the time it appears in the billing data, and second, this method could not be easily linked to care. The new VTE measurement method proposed in this research not only provides timely reports, but also assigns the VTE case to a physician who can use this information to improve patient care.

The new VTE measurement method has been utilized in two different ways in Henry Ford Health System since January 2014. First, a dashboard was created to report VTE rates on a daily basis. Thus, physicians and hospital quality staff can use this dashboard to monitor VTE rates in a timely manner. This near real-time view

of the VTE rates and VTE instances in the hospital enables them to intervene earlier should there be even a small increase in VTE rates in a specific hospital or unit.

Second, a list of all the instances of VTE harm patients is sent to the specialty division heads on a routine basis. Access to this data has enabled them to follow up with specific physicians who have had a higher VTE rate compared to their peers or the general physician group within the system. Moreover, since Henry Ford Hospital is a large teaching hospital, these tools have enabled the physicians to provide timely case specific feedback to residents which enhances education opportunities. Since these cases are fresh and the patients are generally still hospitalized, physicians can effectively review them with their residents and make sure proper care procedures are followed.

The graph below shows a screenshot of the three-month moving average for VTE harm rates in all four main Henry Ford Health System's hospitals. As depicted below, the VTE rate system-wide has decreased from around 1.1% to roughly 0.85% over 2 years' time.
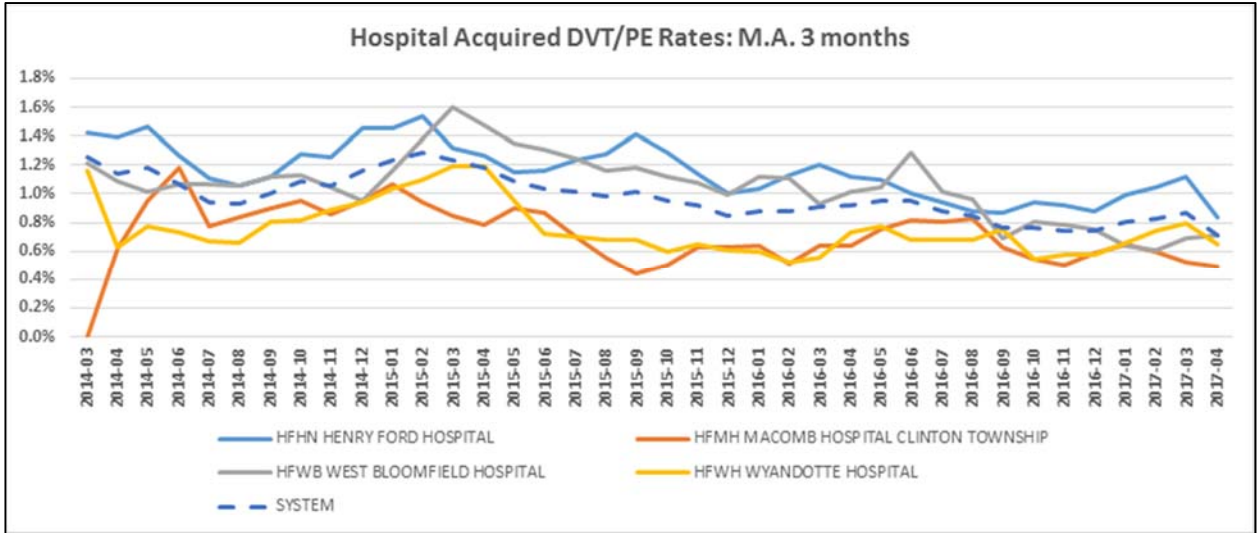
Figure 27 - VTE Harm Dashboard - Showing VTE trends by hospital

Table 15 shows VTE rates by hospital. Total system VTE rates for 2014 and 2015 were 1.09% vs. 0.85% since 2016. The difference is statistically significant using alpha 0.05 with P-Value = 0.0493.

Table 15 - VTE rate by hospital and year

	HFH	HFMH	HWFB	HFWH	SYSTEM
2014	1.35%	0.93%	1.09%	0.82%	1.13%
2015	1.25%	0.71%	1.31%	0.82%	1.06%
2016	1.00%	0.68%	0.93%	0.65%	0.85%
2017 (Q1)	1.13%	0.47%	0.72%	0.70%	0.85%

The decrease in VTE harm is equivalent, on average, to 180 less episodes of hospital acquired VTE annually across the Henry Ford System. Based on studies that suggest 30% of VTE hospital acquired patients suffer mortality within 30 days[33], this decrease is equivalent to 54 lives saved annually. Furthermore, the Institute of

Medicine (IOM) reported that one fifth of the surviving VTE patients experience life-long problems. These include recurrent VTE, post-thrombotic syndrome (PTS), and chronic thromboembolic pulmonary hypertension (CTEPH). This means that the new method can save tens of patients each year from these recurring problems.

Using the 2013 data, the Agency for Healthcare Research and Quality (AHRQ) has estimated that every instance of hospital acquired VTE will cost an additional $8,000 for the hospitals to treat[13]. Considering that hospitals must absorb this cost, the 180 less instances of hospital acquired VTE could mean $1.44 million in savings for the health system. The IOM also reported an additional $14,000 to $17,000 cost for the health plan for each instance of VTE. This suggests that Henry Ford Health System could have saved more than $3 million annually just by decreasing the VTE incidents.

As mentioned before, this study has enabled and supported numerous improvement projects related to VTE across the Henry Ford Health System. Two of the most important projects are trials that were done in HFH and HFWB:

First trial – Henry Ford Hospital

In addition to providing a timely dashboard, this study has supported and enabled two specific trials in Henry Ford Hospital and Henry Ford West Bloomfield

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[13] https://www.ahrq.gov/professionals/quality-patient-safety/pfp/hacrate2013.html

Hospital to decrease VTE harm rates among medically ill patients. The first adoption of the model took place at Henry Ford Hospital. This trial was led by one of the senior internal medicine physicians who realized the value of using the new model and what it had to offer. Having the support of the hospital quality team, he led the trial using the developed model. The efforts were focused around two main areas: resident education and patient education.

- *Resident education*: The senior doctor reviewed all the instances of VTE with his residents in four main medical units to ensure proper medical practices were followed. In addition, every inpatient in those medical floors were reviewed on daily rounds using the Padua model developed in the EHR to ensure at-risk patients either receive medical prophylaxis or have contraindications to receive one.

- *Patient education*: Patients may miss or refuse their medical VTE prophylaxis. This can be because some patients tend to generally avoid any medications unless necessary for them. Also, the Subcutaneous (sub-q) injection of the prophylactic heparin is not very pleasant for the patient. To reduce these instances, a patient brochure was designed to educate patients on VTE and its risks. The benefits and risks of receiving medical prophylaxis were

explained in the brochure. The idea behind designing this brochure is to encourage patients to ensure they receive their medical prophylaxis.

- Below is a copy of this brochure that was designed and used in HFH.

Figure 28 - Patient Education Brochure used at HFH (Front)
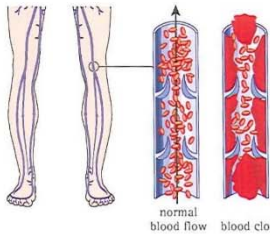
WHAT IS A BLOOD CLOT?

A blood clot is when blood forms a mass in blood vessels that block the flow of blood. It can occur in the legs and in the lungs.

Blood clots found in the legs can form in shallow or deep veins. The good news is leg clots are preventable and treatable if discovered early.

A blood clot found in the lung is a clot that travels to the lung from another location, usually from the leg. If the clot is small, with treatment, people can recover.

A blood clot is a SERIOUS, LIFE THREATENING COMPLICATION that can lead to death.

normal blood flow   blood clot

Remember, Prevention is the Key

WHO IS MOST AT RISK FOR A BLOOD CLOT?
People who:

- Are currently hospitalized
- Have had recent surgery
- Have active or any history of cancer
- Have heart disease
- Have lung disease
- Are over 60 years old
- Are smoking
- Are overweight
- Have an infection
- Have had blood clots before
- Have family who have had blood clots
- Have difficulty moving
- Are taking hormone replacement
- Are taking birth control

These are not all of the risk factors. Talk to your doctor if you think you might be at risk.

HOW CAN I PREVENT BLOOD CLOTS?

1. STAY ACTIVE. GET UP AND WALK!

By walking or doing leg exercises, this will help keep blood flowing in the legs to prevent clots from forming.

If unable to walk during hospitalization, perform the leg exercises provided by your team while lying in bed or sitting in a chair.

2. WEAR SEQUENTIAL COMPRESSION DEVICES (SCD)

This device helps keep the blood moving through the veins of the leg by squeezing them. It is important to wear them at all times when you are not walking. This includes when you are in bed or sitting in a chair.

3. MEDICATION

Your medical team may order a blood-thinning medication to prevent a blood clot. If they do, it may be given as an injection or a pill. It is very important for you to receive the prescribed medication.

WHEN YOU GO HOME FROM THE HOSPITAL

If you have been taking a blood-thinning medication in the hospital, you may be asked to continue it at home. It is very important for you to follow all of your medical team's instructions to reduce your risk of developing a blood clot, even after leaving the hospital.

Figure 29 - Patient Education Brochure used at HFH (Back)

The graph below shows how the initiatives backed up by the proposed model contributed to a decrease in the VTE rates in the selected units. VTE rates decreased from approximately 1.6% to roughly 0.8% over a 2-year period.
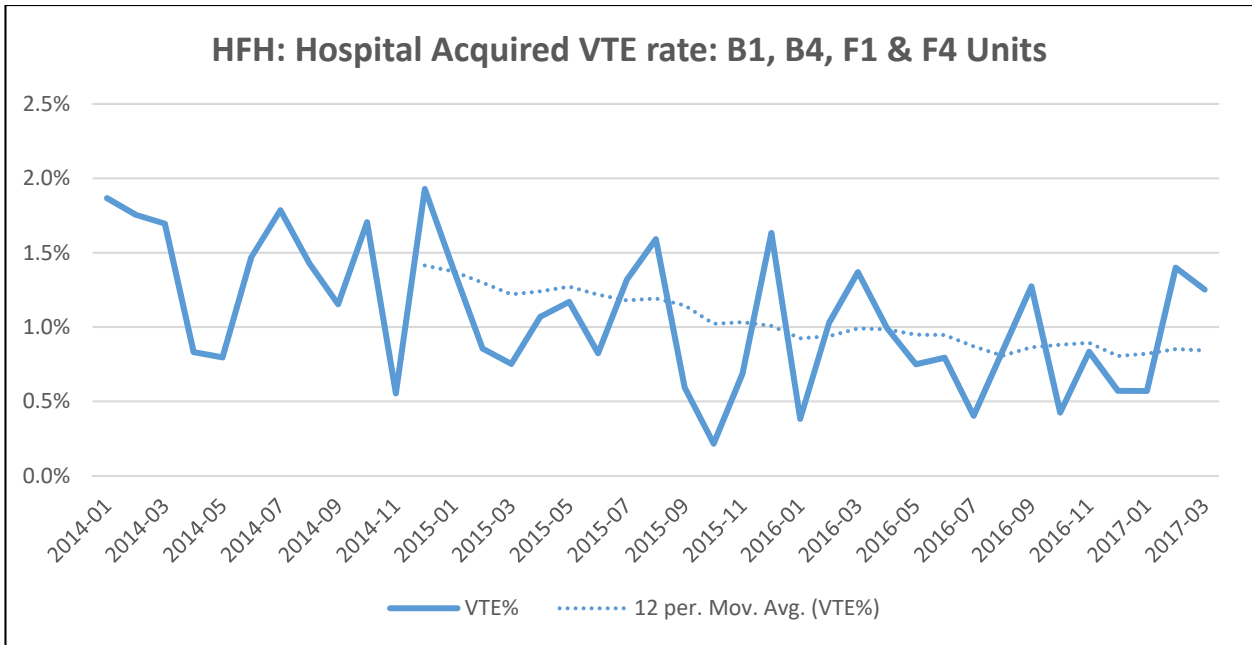
Figure 30 - VTE rates in four main medical units in HFH

Second trial – Henry Ford West Bloomfield Hospital

Following the positive outcomes from the trial in Henry Ford Hospital, Henry Ford West Bloomfield Hospital (HFWB) started an improvement project to reduce VTE rates among their medically ill patients. The main medical units were once again targeted, and potential areas for improvement were discussed. One of the topics that was tackled was adherence to medical prophylaxis. Earlier, this study proved that patients who miss at least one dose of prophylaxis are in a significantly higher risk to get VTEs (Alpha = 0.05 and P-Value < 0.0001). Therefore, the efforts were focused around making sure that all patients receive their medical

prophylaxis when they are ordered one. These efforts were focused on nurses and patients alike.

Table 16 - Prophylaxis Missed and effects on VTE Harm

Number Missed	NO	VTE: POA	VTE Acquired	Total	VTE Rate
None	77087	1721	786	79594	1.0%
At Least Missed Once	21726	185	489	22400	2.2%

- *Nurse education*: A medical prophylaxis report was sent to the group on a regular basis to review medication administration and follow up with nurses to ensure patients receive their medical/mechanical prophylaxis.

- *Patient Education:* A new brochure was designed using the previously designed brochure at HFH. Further efforts were made to ensure that not only patients receive the brochure, but they also read it to understand the risks of VTE.

The graphs below depict the results of these efforts. Patient refusals of medical VTE prophylaxis were reduced by two-thirds from 15% to nearly 5%. In addition, missing those medications for any other reason dropped from 25% to around 11%. These decreases happened over a two-year period.

VTE Prophylaxis (chemical) - Patient Refusals
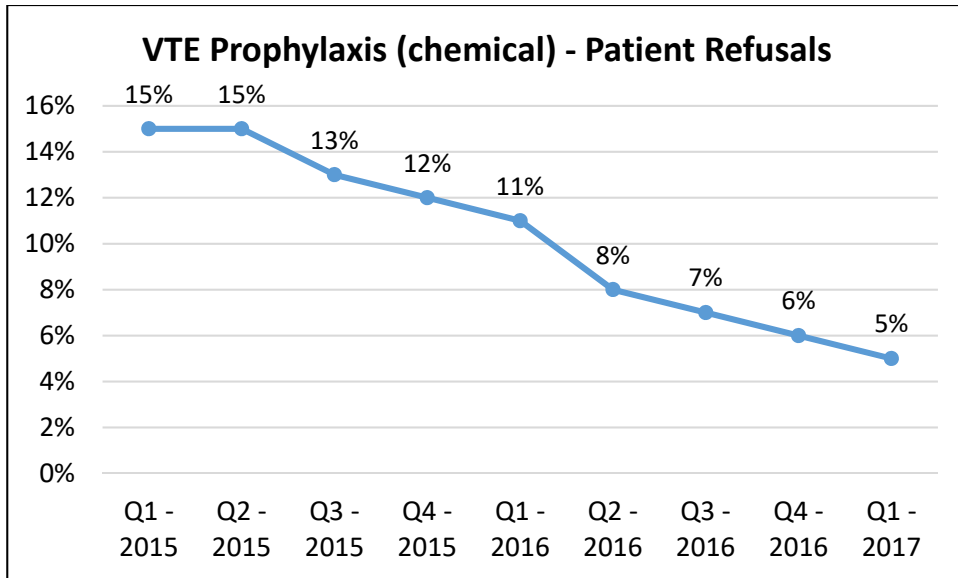
Figure 31 - Patient VTE medical prophylaxis refusals at HFWB

VTE Prophylaxis (chemical) - Missed Doses
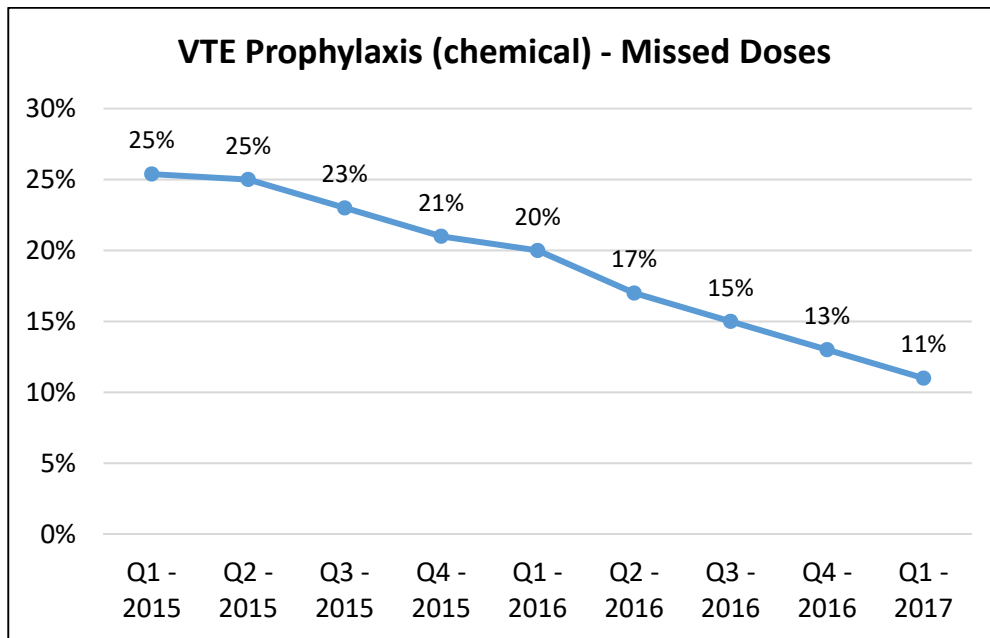
Figure 32 - Patient VTE medical prophylaxis Misses at HFWB

Looking at the raw numbers of VTE instances at HFWB hospital, it shows that VTE

instances decreased by more than half in the same time period. Looking at the

patient population in these units, the VTE rates dropped from approximately 1.3% to nearly 0.6%.

Raw Number of VTE (blood clots) by quarter

Quarter	Value
Q1 - 2015	51
Q2 - 2015	41
Q3 - 2015	49
Q4 - 2015	31
Q1 - 2016	37
Q2- 2016	47
Q3 - 2016	20
Q4 - 2016	25
Q1- 2017	21
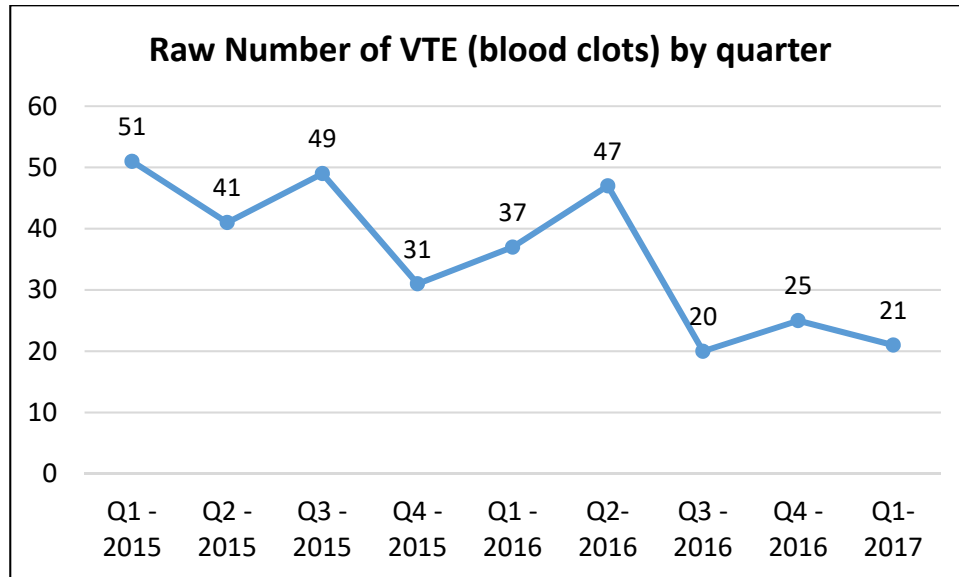
Figure 33 - Quarterly VTE instances in HFWB medical units

VTE Datamart

As part of this study and to support the quality improvement initiatives related to VTEs, a set of VTE data repositories called data marts were developed to perform required retrospective data analysis for designing the VTE risk assessment models. These data marts are updated daily, and currently include more than 270,000 inpatient encounters. The main VTE data mart contains more than 100 variables and captures information such as patient identifiers, patient demographic data, encounter-specific identifiers, and medical characteristics of the patients. These

medical characteristics are mainly designed and obtained to support the development of the Padua risk assessment model. Therefore, all the factors used in the Padua model are captured within the VTE data mart. Along with total prophylaxis and treatments received, missed or refused, the data mart identifies the first physician who ordered the prophylaxis. The system captures the dates compression devices were ordered for the first time as well as the first and last time a nurse documented their use on the patients.

The number of VTE imaging studies done on each patient are also captured including CT chest scans, VQ lung scans, venous Doppler and duplexes. The system also captures Gastrointestinal bleeding problem within the same encounter, and whether the patient is thrombocytopenic.

Two other fields of the data mart are assigned to identify IVC filters using placement orders and problem list. The next six fields are assigned to identify if the patient has any types of lines including peripherally inserted central lines (PICC), central venous catheter (CVC), midline catheter, dialysis catheter, implanted ports and tunneled catheter lines. The total minutes that the patient spends in the emergency department, operating room and under surgery are also included in the data mart. This is followed by an identifier to indicate if the patient was later readmitted to the hospital within 30 days.

There are two data marts developed around VTE medication administration. One of the lists contains every single administration order of any VTE prophylaxis, including the name and type of the drug, time of administration, order frequency and dosage, who ordered the medication, and what happened to the order. The last data mart is basically the same but contains data on VTE treatment medication.

CHAPTER 6 FUTURE RESEARCH OPPORTUNITIES

This chapter discusses a couple of areas of opportunity for future research.

VTE Harm Measurement

- Performing more chart reviews and identifying the status of VTE on an inpatient stay. Capturing the time when VTE identified, physician assignment and other nuances such as prophylaxis contraindications, reasons why patients did not receive prophylaxis including units they are possibly visiting. This can help to not only enhance performance of the model by tweaking it, but also helps improve other functionalities of the model such as physician assignment and determination of time of VTE occurrence.

VTE Risk Assessment:

- Increases the scope of the risk assessment model to go beyond the hospital admissions and understand how hospital care effects the risk of getting a blood clot even after hospital discharge.

- Calculates the risk of acquiring a blood clot as a function of time, to be able to conditionally calculate the risk of the VTE depending on how long a patient has been in the hospital.

APPENDIX

Cancer ICD 9 List - Neoplasms (140–239)

- Malignant neoplasm of lip, oral cavity, and pharynx (140–149)
  - (140) Malignant neoplasm of lip
  - (141) Malignant neoplasm of tongue
  - (142) Malignant neoplasm of major salivary glands
  - (143) Malignant neoplasm of gum
  - (144) Malignant neoplasm of floor of mouth
  - (145) Malignant neoplasm of other and unspecified parts of mouth
  - (146) Malignant neoplasm of oropharynx
  - (147) Malignant neoplasm of nasopharynx
  - (148) Malignant neoplasm of hypopharynx
  - (149) Malignant neoplasm of other and ill-defined sites within the lip
- Malignant neoplasm of digestive organs and peritoneum (150–159)
  - (150) Malignant neoplasm of esophagus
  - (151) Malignant neoplasm of stomach
  - (152) Malignant neoplasm of small intestine, including duodenum
  - (153) Malignant neoplasm colon
  - (154) Malignant neoplasm of rectum, rectosigmoid junction, and anus
  - (155) Malignant neoplasm of liver and intrahepatic bile ducts
  - (156) Malignant neoplasm of gallbladder and extrahepatic bile ducts
  - (157) Malignant neoplasm of pancreas
  - (158) Malignant neoplasm of retroperitoneum and peritoneum
  - (159) Malignant neoplasm of other and ill-defined sites within the
- Malignant neoplasm of respiratory and intrathoracic organs (160–165)
  - (160) Malignant neoplasm of nasal cavities, middle ear, and accessory sinuses
  - (161) Malignant neoplasm of larynx
  - (162) Malignant neoplasm of trachea, bronchus, and lung
    - (162.0) Trachea
    - (162.2) Main bronchus
    - (162.3) Upper lobe, bronchus or lung
    - (162.4) Middle lobe, bronchus or lung
    - (162.5) Lower lobe, bronchus or lung
    - (162.8) Other parts of bronchus or lung

- o (162.9) Bronchus and lung, unspecified
  - (163) Malignant neoplasm of pleura
  - (164) Malignant neoplasm of thymus, heart, and mediastinum
  - (165) Malignant neoplasm of other and ill-defined sites within the respiratory system and intrathoracic organs
- Malignant neoplasm of bone, connective tissue, skin, and breast (170–175)
  - (170) Malignant neoplasm of bone and articular cartilage
  - (170.9) Malignant neoplasm of bone and articular cartilage, site unspecified
    - o Ewing's sarcoma
    - o Osteosarcoma
    - o Chondrosarcoma
  - (171) Malignant neoplasm of connective and other soft tissue
  - Rhabdomyosarcoma
  - (172) Malignant melanoma of skin
  - (173) Other malignant neoplasm of skin
  - (174) Malignant neoplasm of female breast
  - (175) Malignant neoplasm of male breast
- Kaposi's sarcoma (176–176)
  - (176) Kaposi's sarcoma
    - o (176.0) Kaposi's sarcoma skin
    - o (176.1) Kaposi's sarcoma soft tissue
    - o (176.2) Kaposi's sarcoma palate
    - o (176.3) Kaposi's sarcoma gastrointestinal sites
    - o (176.4) Kaposi's sarcoma
    - o (176.5) Kaposi's sarcoma lymph nodes
    - o (176.8) Kaposi's sarcoma other specified sites
    - o (176.9) Kaposi's sarcoma unspecified site
- Malignant neoplasm of genitourinary organs (179–189)
  - (179) Malignant neoplasm of uterus, part unspecified
  - (180) Malignant neoplasm of cervix uteri
  - (181) Malignant neoplasm of placenta
  - (182) Malignant neoplasm of body of uterus
    - o (182.0) Corpus uteri, except isthmus
    - o Endometrial cancer
  - (183) Malignant neoplasm of ovary and other uterine adnexa
  - (184) Malignant neoplasm of other and unspecified female genital organs

- (185) Malignant neoplasm of prostate
- (186) Malignant neoplasm of testis
- (187) Malignant neoplasm of penis and other male genital organs
- (188) Malignant neoplasm of bladder
- (189) Malignant neoplasm of kidney and other and unspecified urinary organs
  - (189.0) Kidney, except pelvis
  - Renal cell carcinoma
- Malignant neoplasm of other and unspecified sites (190–199)
  - (190) Malignant neoplasm of eye
  - (191) Malignant neoplasm of brain
  - (192) Malignant neoplasm of other and unspecified parts of nervous system
    - (192.0) Cranial nerve
    - (192.1) Cerebral meninges
    - Meningioma
    - (192.2) Spinal cord
    - (192.3) Spinal meninges
  - (193) Malignant neoplasm of thyroid gland
  - (194) Malignant neoplasm of other endocrine glands and related structures
  - (195) Malignant neoplasm of other and ill-defined sites
  - (196) Secondary and unspecified malignant neoplasm of lymph nodes
  - (197) Secondary malignant neoplasm of respiratory and digestive systems
  - (198) Secondary malignant neoplasm of other specified sites
  - (199) Malignant neoplasm without specification of site
- Malignant neoplasm of lymphatic and hematopoietic tissue (200–208)
  - (200) Lymphosarcoma and reticulosarcoma
    - (200.0) Reticulosarcoma
    - (200.1) Lymphosarcoma
    - (200.2) Burkitt's tumor or lymphoma
    - (200.3) Marginal zone lymphoma
    - (200.4) Mantle cell lymphoma
    - (200.5) Primary central nervous system lymphoma
    - (200.6) Anaplastic large cell lymphoma
    - (200.7) Large cell lymphoma

- o (200.8) Other named variants of lymphosarcoma and reticulosarcoma
  - (201) Hodgkin's disease
  - (202) Other malignant neoplasms of lymphoid and histiocytic tissue
    - o (202.0) Nodular lymphoma
    - o (202.1) Mycosis fungoides
    - o (202.2) Sézary's disease
    - o (202.3) Malignant histiocytosis
    - o (202.4) Leukemic reticuloendotheliosis (commonly called hairy cell leukemia)
    - o (202.5) Letterer-Siwe disease
    - o (202.6) Malignant mast cell tumors
    - o (202.7) Peripheral T-cell lymphoma
    - o (202.8) Other lymphomas
    - o (202.9) Other and unspecified malignant neoplasms of lymphoid and histiocytic tissue
  - (203) Multiple myeloma and immunoproliferative neoplasms
  - (203.0) Multiple myeloma
  - (204) Lymphoid leukemia
    - o (204.0) Acute lymphoblastic leukemia
    - o (204.1) Chronic lymphocytic leukemia
  - (205) Myeloid leukemia
    - o (205.0) Acute myelogenous leukemia
    - o (205.1) Chronic myelogenous leukemia
  - (206) Monocytic leukemia
  - (207) Other specified leukemia
    - o (207.0) Acute erythremia and erythroleukemia
    - o (207.1) Chronic erythremia
    - o (207.2) Megakaryocytic leukemia
  - (208) Leukemia of unspecified cell type
- Neuroendocrine tumors (209–209)
  - (209) Neuroendocrine tumors
    - o (209.0) Malignant carcinoid tumors of the small intestine
    - o (209.1) Malignant carcinoid tumors of the appendix, large intestine, and rectum
    - o (209.2) Malignant carcinoid tumors of other and unspecified sites
    - o (209.3) Malignant poorly differentiated neuroendocrine carcinoma

- o (209.4) Benign carcinoid tumors of the small intestine
- o (209.5) Benign carcinoid tumors of the appendix, large intestine, and rectum
- o (209.6) Benign carcinoid tumors of other and unspecified sites
- Benign neoplasms (210–229)
  - (210) Benign neoplasm of lip, oral cavity, and pharynx
  - (211) Benign neoplasm of other parts of digestive system
    - o (211.3) Colon
    - o Familial adenomatous polyposis
  - (212) Benign neoplasm of respiratory and intrathoracic organs
    - o (212.0) Nasal cavities middle ear and accessory sinuses
    - o (212.1) Larynx
    - o (212.2) Trachea
    - o (212.3) Bronchus and lung
    - o (212.4) Pleura
    - o (212.5) Mediastinum
    - o (212.6) Thymus
    - o (212.7) Heart
    - o Myxoma
    - o Rhabdomyoma
  - (213) Benign neoplasm of bone and articular cartilage
    - o (213.9) Bone and articular cartilage, site unspecified
    - o Chondroma
  - (214) Lipoma
  - (215) Other benign neoplasm of connective and other soft tissue
  - (216) Benign neoplasm of skin
  - Melanocytic nevus
  - (217) Benign neoplasm of breast
  - (218) Uterine leiomyoma
  - (219) Other benign neoplasm of uterus
  - (220) Benign neoplasm of ovary
  - (221) Benign neoplasm of other female genital organs
  - (222) Benign neoplasm of male genital organs
  - (223) Benign neoplasm of kidney and other urinary organs
  - (224) Benign neoplasm of eye
  - (225) Benign neoplasm of brain and other parts of nervous system
  - (226) Benign neoplasm of thyroid glands

- ▪ (227) Benign neoplasm of other endocrine glands and related structures
- ▪ (228) Hemangioma and lymphangioma, any site
  - o (228.0) Hemangioma, any site
  - o (228.1) Lymphangioma, any site
- ▪ (229) Benign neoplasm of other and unspecified sites
- Carcinoma in situ (230–234)
  - ▪ (230) Carcinoma in situ of digestive organs
  - ▪ (231) Carcinoma in situ of respiratory system
  - ▪ (232) Carcinoma in situ of skin
  - ▪ (233) Carcinoma in situ of breast and genitourinary system
  - ▪ (234) Carcinoma in situ of other and unspecified sites
- Neoplasms of uncertain behavior (235–238)
  - ▪ (235) Neoplasm of uncertain behavior of digestive and respiratory systems
  - ▪ (236) Neoplasm of uncertain behavior of genitourinary organs
  - ▪ (237) Neoplasm of uncertain behavior of endocrine glands and nervous system
    - o (237.0) Pituitary gland and craniopharyngeal duct
    - o Pituitary adenoma
    - o (237.7) Neurofibromatosis
  - ▪ (238) Neoplasm of uncertain behavior of other and unspecified sites and tissues
    - o (238.4) Polycythemia vera
- Neoplasms of unspecified nature (239–239)
  - ▪ (239) Neoplasms of unspecified nature
    - o (239.2) Skin, soft tissue neoplasm, unspecified

Cancer ICD 10 List

- (C00–C14) Malignant neoplasms, lip, oral cavity and pharynx
  - ▪ (C00) Malignant neoplasm of lip
  - ▪ (C01) Malignant neoplasm of base of tongue
  - ▪ (C02) Malignant neoplasm of other and unspecified parts of tongue
  - ▪ (C03) Malignant neoplasm of gum
  - ▪ (C04) Malignant neoplasm of floor of mouth
  - ▪ (C05) Malignant neoplasm of palate
  - ▪ (C06) Malignant neoplasm of other and unspecified parts of mouth

- ▪ (C07) Malignant neoplasm of parotid gland
- ▪ (C08) Malignant neoplasm of other and unspecified major salivary glands
- ▪ (C09) Malignant neoplasm of tonsil
- ▪ (C10) Malignant neoplasm of oropharynx
- ▪ (C11) Malignant neoplasm of nasopharynx
- ▪ (C12) Malignant neoplasm of piriform sinus
- ▪ (C13) Malignant neoplasm of hypopharynx
- ▪ (C14) Malignant neoplasm of other and ill-defined sites in the lip, oral cavity and pharynx
- • (C15–C26) Malignant neoplasms, digestive organs
  - ▪ (C15) Malignant neoplasm of Esophagus
  - ▪ (C16) Malignant neoplasm of Stomach
    - o (C16.0) Cardia
    - o (C16.1) Fundus of stomach
    - o (C16.2) Body of stomach
    - o (C16.3) Pyloric antrum
    - o (C16.4) Pylorus
    - o (C16.5) Lesser curvature of stomach, unspecified
    - o (C16.6) Greater curvature of stomach, unspecified
    - o (C16.8) Overlapping lesion of stomach
    - o (C16.9) Stomach, unspecified
  - ▪ (C17) Malignant neoplasms of small intestine
    - o (C17.0) Duodenum
    - o (C17.1) Jejunum
    - o (C17.2) Ileum
    - o (C17.3) Meckel's diverticulum
    - o (C17.8) Overlapping lesion of small intestine
    - o (C17.9) Small intestine, unspecified
  - ▪ (C18) Malignant neoplasm of colon
    - o (C18.0) Caecum
    - o (C18.1) Appendix
    - o (C18.2) Ascending colon
    - o (C18.3) Hepatic flexure
    - o (C18.4) Transverse colon
    - o (C18.5) Splenic flexure
    - o (C18.6) Descending colon
    - o (C18.7) Sigmoid colon

- - - o (C18.8) Overlapping lesion of colon
    - o (C18.9) Colon, unspecified
  - (C19) Malignant neoplasm of rectosigmoid junction
  - (C20) Malignant neoplasm of rectum
  - (C21) Malignant neoplasms of anus and anal canal
  - (C22) Malignant neoplasms of liver and intrahepatic bile ducts
    - o (C22.0) Liver cell carcinoma
    - o (C22.1) Intrahepatic bile duct carcinoma
    - o (C22.2) Hepatoblastoma
    - o (C22.3) Angiosarcoma of liver
    - o (C22.4) Other sarcomas of liver
    - o (C22.7) Other specified carcinomas of liver
    - o (C22.9) Liver, unspecified
  - (C23) Malignant neoplasm of gallbladder
  - (C24) Malignant neoplasm of other and unspecified parts of biliary tract
  - (C25) Malignant neoplasm of pancreas
  - (C25.0) Head of pancreas
    - o (C25.1) Body of pancreas
    - o (C25.2) Tail of pancreas
    - o (C25.3) Pancreatic duct
    - o (C25.4) Endocrine pancreas
    - o (C25.7) Other parts of pancreas
    - o (C25.8) Overlapping lesion of pancreas
    - o (C25.9) Pancreas, unspecified
  - (C26) Malignant neoplasms of other and ill-defined Digestive Organs
- (C30–C39) Malignant neoplasms, respiratory system and intrathoracic organs
  - (C30) Malignant neoplasm of nasal cavity and middle ear
    - o (C30.0) Nasal cavity
    - o (C30.1) Middle ear
  - (C31) Malignant neoplasm of accessory sinuses
  - (C32) Malignant neoplasm of larynx
  - (C33) Malignant neoplasm of trachea
  - (C34) Malignant neoplasm of bronchus and lung
    - o (C34.0) Main bronchus
    - o (C34.1) Upper lobe, bronchus or lung
    - o Pancoast tumor
    - o (C34.2) Middle lobe, bronchus or lung

- o (C34.3) Lower lobe, bronchus or lung
- o (C34.8) Overlapping lesion of bronchus and lung
  - ▪ (C37) Malignant neoplasm of thymus
  - ▪ (C38) Malignant neoplasm of heart, mediastinum and pleura
    - o (C38.0) Heart
    - o (C38.1) Anterior mediastinum
    - o (C38.2) Posterior mediastinum
    - o (C38.3) Mediastinum, part unspecified
    - o (C38.4) Pleura
    - o (C38.8) Overlapping lesion of heart, mediastinum and pleura
  - ▪ (C39) Malignant neoplasms of other and ill-defined sites in respiratory system and intrathoracic organs
- (C40–C41) Malignant neoplasms, bone and articular cartilage
  - ▪ (C40) Malignant neoplasm of bone and articular cartilage of limbs
  - ▪ (C41) Malignant neoplasm of bone and articular cartilage of other and unspecified sites
- (C43–C44) Malignant neoplasms, skin
  - ▪ (C43) Malignant melanoma of Skin
  - ▪ (C44) Other malignant neoplasms of skin
- (C45–C49) Malignant neoplasms, connective and soft tissue
  - ▪ (C45) Mesothelioma
  - ▪ (C46) Kaposi's Sarcoma
  - ▪ (C47) Malignant neoplasm of peripheral nerves and autonomic nervous system
  - ▪ (C48) Malignant neoplasm of retroperitoneum and peritoneum
    - o (C48.0) Retroperitoneum
    - o (C48.1) Specified parts of peritoneum
    - o (C48.2) Peritoneum, unspecified
  - ▪ (C49) Malignant neoplasm of other connective and soft tissue
    - o C49.M10 Malignant fibrous histiocytoma
    - o C49.M12 Atypical fibroxanthoma
    - o C49.M20 Haemangiopericytoma
    - o C49.M22 Angioendotheliomatosis, malignant
    - o C49.M24 Dermatofibrosarcoma protruberans
    - o C49.M30 Bednar tumour
    - o C49.M40 Sarcoma of skin
    - o C49.M42 Fibrosarcoma

- o C49.M44 Schwannoma, malignant
- o C49.M48 Leiomyosarcoma
- o C49.M50 Rhabdomyosarcoma
- o C49.M54 Myxofibrosarcoma
- o C49.M60 Angiosarcoma, cutaneous
- o C49.M70 Lymphangiosarcoma
- (C50–C58) Malignant neoplasms, breast and female genital organs
  - (C50) Malignant neoplasm of breast
  - (C51) Malignant neoplasm of vulva
  - (C52) Malignant neoplasm of vagina
  - (C53) Malignant neoplasm of cervix uteri
  - (C54) Malignant neoplasm of corpus uteri
    - o (C54.1) Endometrial cancer
  - (C55) Malignant neoplasm of uterus, part unspecified
  - (C56) Malignant neoplasm of ovary
  - (C57) Malignant neoplasms of other and unspecified female and genital organs
  - (C58) Malignant neoplasm of placenta
    - o Choriocarcinoma
    - o Chorionepithelioma NOS
- (C60–C63) Malignant neoplasms of male genital organs
  - (C60) Malignant neoplasm of penis
  - (C61) Malignant neoplasm of prostate
  - (C62) Malignant neoplasm of testis
  - (C63) Malignant neoplasm of other and unspecified male genital organs
- (C64–C68) Malignant neoplasms, urinary organs
  - (C64) Malignant neoplasm of kidney, except renal pelvis
  - Wilms' tumor
  - (C65) Malignant neoplasm of renal pelvis
  - (C66) Malignant neoplasm of ureter
  - (C67) Malignant neoplasm of bladder
  - (C68) Malignant neoplasm of other and unspecified urinary organs
- (C69–C72) Malignant neoplasms, eye, brain and central nervous system
  - (C69) Malignant neoplasms of eye and adnexa
    - o (C69.0) Conjunctiva
    - o (C69.1) Cornea
    - o (C69.2) Retina

- o Retinoblastoma
- o (C69.3) Choroid
- o (C69.4) Ciliary body
- o (C69.5) Lacrimal gland and duct
- o (C69.6) Orbit
- o (C69.7) Overlapping lesion of eye and adnexa
- (C70) Malignant neoplasm of meninges
  - o (C70.0) Cerebral meninges
  - o (C70.1) Spinal meninges
- (C71) Malignant neoplasm of brain
  - o (C71.0) Cerebrum, except lobes and ventricles
  - o (C71.1) Frontal lobe
  - o (C71.2) Temporal lobe
  - o (C71.3) Parietal lobe
  - o (C71.4) Occipital lobe
  - o (C71.5) Cerebral ventricle
  - o (C71.6) Cerebellum
  - o (C71.7) Brain stem
  - o (C71.8) Overlapping lesion of brain
  - o (C71.9) Brain, unspecified
- (C72) Malignant neoplasm of spinal cord, cranial nerves and other parts of central nervous system
  - o (C72.0) Spinal cord
  - o (C72.1) Cauda equina
  - o (C72.2) Olfactory nerve
  - o (C72.3) Optic nerve
  - o (C72.4) Acoustic nerve
  - o (C72.5) Other and unspecified cranial nerves
  - o (C72.8) Overlapping lesion of brain and other parts of central nervous system
  - o (C72.9) Central nervous system, unspecified
- (C73–C75) Malignant neoplasms, endocrine glands and related structures
  - (C73) Malignant neoplasm of thyroid gland
  - (C74) Malignant neoplasm of adrenal gland
    - o (C74.0) Cortex of adrenal gland
    - o (C74.1) Medulla of adrenal gland
    - o Pheochromocytoma

- o (C74.9) Adrenal gland, unspecified
- o Neuroblastoma, NOS
  - ▪ (C75) Malignant neoplasm of other endocrine glands and related structures
- (C76–C80) Malignant neoplasms, secondary and ill-defined
  - ▪ (C76) Malignant neoplasm of other and ill-defined sites
    - o (C76.0) Langerhans' cell histiocytosis, not elsewhere classified
    - o (C76.1) Haemophagocytic lymphohistiocytosis
    - o (C76.2) Haemophagocytic syndrome, infection-associated
    - o (C76.3) Other histiocytosis syndromes
  - ▪ (C77) Secondary and unspecified malignant neoplasm of lymph nodes
  - ▪ (C78) Secondary malignant neoplasm of respiratory and digestive organs
  - ▪ (C79) Secondary malignant neoplasm of other sites
  - ▪ (C80) Malignant neoplasm without specification of site
- (C81–C96) Malignant neoplasms, stated or presumed to be primary, of lymphoid, haematopoietic and related tissue
  - ▪ (C81) Hodgkin's Disease
    - o (C81.0) Lymphocytic predominance
    - o (C81.1) Nodular sclerosis
    - o (C81.2) Mixed cellularity
    - o (C81.3) Lymphocytic depletion
  - ▪ (C82) Follicular non-Hodgkin's lymphoma (nodular)
    - o (C82.0) Small cleaved cell, follicular
    - o (C82.1) Mixed small cleaved and large cell, follicular
    - o (C82.2) Large cell, follicular
  - ▪ (C83) Diffuse non-Hodgkin's lymphoma
    - o (C83.0) small cell (diffuse)
    - o (C83.1) Small cleaved cell (diffuse)
    - o (C83.2) Mixed small and large cell (diffuse)
    - o (C83.3) large cell (diffuse)
    - o (C83.4) Immunoblastic (diffuse)
    - o (C83.5) Lymphoblastic (diffuse)
    - o (C83.6) Undifferentiated (diffuse)
    - o (C83.7) Burkitt's tumour
  - ▪ (C84) Peripheral and cutaneous T-cell lymphomas
    - o (C84.0) Mycosis fungoides
    - o (C84.1) Sézary's disease

- o (C84.2) T-zone lymphoma
- o (C84.3) Lymphoepitheliod lymphoma
- o (C84.4) Peripheral T-cell lymphoma
- (C85) Other and unspecified types of non-Hodgkin's lymphoma
  - o (C85.0) Lymphosarcoma
  - o (C85.1) B-cell lymphoma, unspecified
- (C88) Malignant immunoproliferative diseases
  - o (C88.0) Waldenström's macroglobulinaemia
  - o (C88.1) Alpha heavy chain disease
  - o (C88.2) Gamma heavy chain disease
  - o (C88.3) Immunoproliferative small intestinal disease
- (C90) Multiple myeloma and malignant plasma cell neoplasms
  - o (C90.0) Multiple myeloma
  - o (C90.1) Plasma cell leukemia
  - o (C90.2) Plasmacytoma, extramedullary
- (C91) Lymphoid leukemia
  - o (C91.0) Acute lymphoblastic leukemia
  - o (C91.1) Chronic lymphocytic leukemia
  - o (C91.4) Hairy cell leukemia
- (C92) Myeloid leukemia
  - o (C92.0) Acute myeloid leukemia
  - o (C92.1) Chronic myeloid leukemia
  - o (C92.2) Subacute myeloid leukemia
  - o (C92.3) Myeloid sarcoma
  - o Chloroma
  - o Granulocytic sarcoma
  - o (C92.4) Acute promyelocytic leukemia
  - o (C92.5) Acute myelomonocytic leukemia
- (C93) Monocytic leukemia
  - o (C93.0) Acute monocytic leukemia
  - o (C93.1) Chronic monocytic leukemia
  - o (C93.2) Subacute monocytic leukemia
- (C94) Other leukemias of specified cell type
  - o (C94.0) Acute erythraemia and erythroleukemia
  - o Di Guglielmo's disease
  - o (C94.1) Chronic erythraemia
  - o (C94.2) Acute megakaryoblastic leukemia

- o (C94.3) Mast cell leukemia
- o (C94.4) Acute panmyelosis
- o (C94.5) Acute myelofibrosis
- o (C94.7) Other specified leukemias
  - (C95) Leukemia of unspecified cell type
  - (C95.0) Acute leukemia of unspecified cell type
  - (C95.1) Chronic leukemia of unspecified cell type
  - (C95.2) Subacute leukemia of unspecified cell type
  - (C95.7) Other leukemia of unspecified cell type
  - (C95.9) Leukemia, unspecified
  - (C96) Other and unspecified malignant neoplasms of lymphoid, haematopoietic and related tissue
  - (C96.0) Letterer-Siwe disease
  - (C96.1) Malignant histiocytosis
  - (C96.2) Malignant mast cell tumour
  - Malignant mastocytosis
  - (C96.3) True histiocytic lymphoma
  - (C96.7) Other specified malignant neoplasms of lymphoid, haematopoietic and related tissue
  - (C96.9) Malignant neoplasm of lymphoid, haematopoietic and related tissue, unspecified
- (C97) Malignant neoplasms of independent (primary) multiple sites

Previous VTE ICD 9 List

- (415.1) Pulmonary embolism and infarction
- (415.11) Iatrogenic pulmonary embolism and infarction
- (415.13) Saddle embolus of pulmonary artery
- (451.11) Phlebitis and thrombophlebitis of femoral vein (deep) (superficial)
- (415.19) Phlebitis and thrombophlebitis of deep veins of lower extremities, other
- (451.2) Phlebitis and thrombophlebitis of lower extremities, unspecified
- (451.81) Phlebitis and thrombophlebitis of iliac vein
- (451.9) Phlebitis and thrombophlebitis of unspecified site
- (453.4) Acute venous embolism and thrombosis of deep vessels of lower extremity

- (453.40) Acute venous embolism and thrombosis of deep vessels of lower extremity
- (453.41) Acute venous embolism and thrombosis of deep vessels of proximal lower extremity
- (453.42) Acute venous embolism and thrombosis of deep vessels of distal lower extremity
- (453.8) Acute venous embolism and thrombosis of other specified veins
- (453.9) Other venous embolism and thrombosis of unspecified site

Previous VTE ICD 10 List

- (I80.1) Phlebitis and thrombophlebitis of femoral vein
  - (I80.10) Phlebitis and thrombophlebitis of unspecified femoral vein
  - (I80.11) Phlebitis and thrombophlebitis of right femoral vein
  - (I80.12) Phlebitis and thrombophlebitis of left femoral vein
  - (I80.13) Phlebitis and thrombophlebitis of bilateral femoral vein
- (I80.20) Phlebitis and thrombophlebitis of unspecified deep vessels of lower extremities
  - (I80.201) Phlebitis and thrombophlebitis of unspecified deep vessels of right lower extremity
  - (I80.202) Phlebitis and thrombophlebitis of unspecified deep vessels of left lower extremity
  - (I80.203) Phlebitis and thrombophlebitis of unspecified deep vessels of bilateral lower extremity
  - (I80.209) Phlebitis and thrombophlebitis of unspecified deep vessels of unspecified lower extremity
- (I80.21) Phlebitis and thrombophlebitis of iliac vein
  - (I80.211) Phlebitis and thrombophlebitis of right iliac vein
  - (I80.212) Phlebitis and thrombophlebitis of left iliac vein
  - (I80.213) Phlebitis and thrombophlebitis of bilateral iliac vein
  - (I80.219) Phlebitis and thrombophlebitis of unspecified iliac vein
- (I80.22) Phlebitis and thrombophlebitis of popliteal vein
  - (I80.221) Phlebitis and thrombophlebitis of right popliteal vein
  - (I80.222) Phlebitis and thrombophlebitis of left popliteal vein
  - (I80.223) Phlebitis and thrombophlebitis of bilateral popliteal vein
  - (I80.229) Phlebitis and thrombophlebitis of unspecified popliteal vein
- I80.23 Phlebitis and thrombophlebitis of tibial vein

- ▪ (I80.231) Phlebitis and thrombophlebitis of right tibial vein
- ▪ (I80.232) Phlebitis and thrombophlebitis of left tibial vein
- ▪ (I80.233) Phlebitis and thrombophlebitis of bilateral tibial vein
- ▪ (I80.239) Phlebitis and thrombophlebitis of unspecified tibial vein
- • (I80.29) Phlebitis and thrombophlebitis of other deep vessels of lower extremities
    - ▪ (I80.291) Phlebitis and thrombophlebitis of other deep vessels of right lower extremity
    - ▪ (I80.292) Phlebitis and thrombophlebitis of other deep vessels of left lower extremity
    - ▪ (I80.293) Phlebitis and thrombophlebitis of other deep vessels of lower extremity, bilateral
    - ▪ (I80.299) Phlebitis and thrombophlebitis of other deep vessels of unspecified lower extremity
- • (I82.4) Acute embolism and thrombosis of unspecified deep veins of lower extremity
    - ▪ (I82.401) Acute embolism and thrombosis of unspecified deep veins of right lower extremity
    - ▪ (I82.402) Acute embolism and thrombosis of unspecified deep veins of left lower extremity
    - ▪ (I82.403) Acute embolism and thrombosis of unspecified deep veins of bilateral lower extremity
    - ▪ (I82.409) Acute embolism and thrombosis of unspecified deep veins of unspecified lower extremity
    - ▪ (I82.411) Acute embolism and thrombosis of right femoral vein
    - ▪ (I82.412) Acute embolism and thrombosis of left femoral vein
    - ▪ (I82.413) Acute embolism and thrombosis of bilateral femoral vein
    - ▪ (I82.419) Acute embolism and thrombosis of unspecified femoral vein
- • (I82.42) Acute embolism and thrombosis of iliac vein
    - ▪ (I82.421) Acute embolism and thrombosis of right iliac vein
    - ▪ (I82.422) Acute embolism and thrombosis of left iliac vein
    - ▪ (I82.423) Acute embolism and thrombosis of bilateral iliac vein
    - ▪ (I82.429) Acute embolism and thrombosis of unspecified iliac vein
- • (I82.43) Acute embolism and thrombosis of popliteal vein
    - ▪ (I82.431) Acute embolism and thrombosis of right popliteal vein
    - ▪ (I82.432) Acute embolism and thrombosis of left popliteal vein
    - ▪ (I82.433) Acute embolism and thrombosis of bilateral popliteal vein

- ▪ (I82.439) Acute embolism and thrombosis of unspecified popliteal vein
- • (I82.44) Acute embolism and thrombosis of tibial vein
  - ▪ (I82.441) Acute embolism and thrombosis of right tibial vein
  - ▪ (I82.442) Acute embolism and thrombosis of left tibial vein
  - ▪ (I82.443) Acute embolism and thrombosis of bilateral tibial vein
  - ▪ (I82.449) Acute embolism and thrombosis of unspecified tibial vein
- • (I82.49) Acute embolism and thrombosis of other specified deep vein of lower extremity
  - ▪ (I82.491) Acute embolism and thrombosis of other specified deep vein of right lower extremity
  - ▪ (I82.492) Acute embolism and thrombosis of other specified deep vein of left lower extremity
  - ▪ (I82.493) Acute embolism and thrombosis of other specified deep vein of bilateral lower extremity
  - ▪ (I82.499) Acute embolism and thrombosis of other specified deep vein of unspecified lower extremity
- • (I82.4Y) Acute embolism and thrombosis of unspecified deep veins of proximal lower extremity
  - ▪ (I82.4Y1) Acute embolism and thrombosis of unspecified deep veins of right proximal lower extremity
  - ▪ (I82.4Y2) Acute embolism and thrombosis of unspecified deep veins of left proximal lower extremity
  - ▪ (I82.4Y3) Acute embolism and thrombosis of unspecified deep veins of bilateral proximal lower extremity
  - ▪ (I82.4Y9) Acute embolism and thrombosis of unspecified deep veins of unspecified proximal lower extremity
- • (I82.4Z) Acute embolism and thrombosis of unspecified deep veins of distal lower extremity
  - ▪ (I82.4Z1) Acute embolism and thrombosis of unspecified deep veins of right distal lower extremity
  - ▪ (I82.4Z2) Acute embolism and thrombosis of unspecified deep veins of left distal lower extremity
  - ▪ (I82.4Z3) Acute embolism and thrombosis of unspecified deep veins of left distal bilateral extremity
  - ▪ (I82.4Z9) Acute embolism and thrombosis of unspecified deep veins of unspecified distal lower extremity
  - ▪ (I26.02) Saddle embolus of pulmonary artery with acute cor pulmonale

- (I26.09) Other pulmonary embolism with acute cor pulmonale
- (I26.92) Saddle embolus of pulmonary artery without acute cor pulmonale
- (I26.99) Other pulmonary embolism without acute cor pulmonale

Acute Rheumatologic Disorder ICD9 List

- (390) RHEUMATIC FEVER WITHOUT HEART INVOLVEMENT
- (391.0) ACUTE RHEUMATIC PERICARDITIS
- (391.1) ACUTE RHEUMATIC ENDOCARDITIS
- (391.2) ACUTE RHEUMATIC MYOCARDITIS
- (391.8) OTHER ACUTE RHEUMATIC HEART DISEASE
- (391.9) ACUTE RHEUMATIC HEART DISEASE UNSPECIFIED
- (392.0) RHEUMATIC CHOREA WITH HEART INVOLVEMENT
- (392.9) RHEUMATIC CHOREA WITHOUT HEART INVOLVEMENT
- (393) CHRONIC RHEUMATIC PERICARDITIS
- (394.0) MITRAL STENOSIS
- (394.1) RHEUMATIC MITRAL INSUFFICIENCY
- (394.2) MITRAL STENOSIS WITH INSUFFICIENCY
- (394.9) OTHER AND UNSPECIFIED MITRAL VALVE DISEASES
- (395.0) RHEUMATIC AORTIC STENOSIS
- (395.1) RHEUMATIC AORTIC INSUFFICIENCY
- (395.2) RHEUMATIC AORTIC STENOSIS WITH INSUFFICIENCY
- (395.9) OTHER AND UNSPECIFIED RHEUMATIC AORTIC DISEASES
- (396.0) MITRAL VALVE STENOSIS AND AORTIC VALVE STENOSIS
- (396.1) MITRAL VALVE STENOSIS AND AORTIC VALVE INSUFFICIENCY
- (396.2) MITRAL VALVE INSUFFICIENCY AND AORTIC VALVE STENOSIS
- (396.3) MITRAL VALVE INSUFFICIENCY AND AORTIC VALVE INSUFFICIENCY
- (396.8) MULTIPLE INVOLVEMENT OF MITRAL AND AORTIC VALVES
- (396.9) MITRAL AND AORTIC VALVE DISEASES UNSPECIFIED
- (397.0) DISEASES OF TRICUSPID VALVE
- (397.1) RHEUMATIC DISEASES OF PULMONARY VALVE
- (397.9) RHEUMATIC DISEASES OF ENDOCARDIUM VALVE UNSPECIFIED
- (398.0) RHEUMATIC MYOCARDITIS
- (398.90) RHEUMATIC HEART DISEASE UNSPECIFIED
- (398.91) RHEUMATIC HEART FAILURE (CONGESTIVE)
- (398.99) OTHER RHEUMATIC HEART DISEASES

Acute Rheumatologic Disorder ICD10 List

- (I00) Rheumatic fever without heart involvement
- (I01) Rheumatic fever with heart involvement
- (I02) Rheumatic chorea
- (I05) Rheumatic mitral valve diseases
- (I06) Rheumatic aortic valve diseases
- (I07) Rheumatic tricuspid valve diseases
- (I08) Multiple valve diseases
- (I09) Other rheumatic heart diseases

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ABSTRACT

VENOUS THROMBOEMBOLISM (VTE) HARM MEASUREMENT AND RISK ASSESSMENT IN REAL-TIME USING ELECTRONIC HEALTH RECORDS(EHR)

by

SEYED MANI MARASHI

May 2018

Advisor: Dr. Kenneth Chelst

Major: Industrial and Systems Engineering

Degree: Doctor of Philosophy

Venous Thromboembolism (VTE) is a deadly disease and is considered as one of the top reasons for avoidable hospital deaths in the United States and around the world. Patients who survive this disease often must face life-long complications such as Post-thrombotic syndrome (PTS), Chronic thromboembolic pulmonary hypertension (CTPH), etc. Therefore, it is important to monitor and reduce the number of VTE instances in hospitals. This study shows how Electronic Health Records (EHRs) can be utilized to achieve this goal.

First, a new near real-time VTE harm measurement model was developed. Not only the developed model can deliver near real-time results, but also it can

outperform the existing PSI12 measurement model that uses administrative data (sensitivity 84% vs. 38% and NPV 99% vs. 95%).

In the next step, Padua VTE risk assessment model was developed inside the EHR to deliver real-time VTE risk assessment. Retrospective data analysis was also performed to show how another risk assessment model (IMPROVE) can be developed inside EHR. Analysis were completed to show and compare the effectiveness of each model.

Finally, the results of utilizing the developed models are presented in terms of contributions to savings for the health system as well as the number of lives saved.

AUTOBIOGRAPHICAL STATEMENT

Before I started my PhD program at Wayne State University, I decided that I wanted to choose a research topic that would have an impact on people's lives. It was important for me to work on something practical and applicable rather than a high level theoretical work. Fortunately, Professor Chelst-my PhD advisor- agreed to the idea, and as a result we started looking for a project to start my work. A year later, I knew I was going to work on reducing VTEs.

As a child, I was always fascinated with the medical field. As a matter of fact, I always wanted to become a cardiac or a neuro surgeon, and as we know, it has not become a reality so far. I liked the selected research topic because it was somehow related to my childhood dreams. Soon after, I realized how I know almost nothing about hospital care processes and specifically VTEs. Thankfully, I had someone like Jack Jordan who mentored me and taught me so many things that I needed for my research project. The health care industry also presented challenges that I had to quickly learn and overcome during this project.

Three years has passed since I started this journey. Not only my work could contribute to saving lives but also, I have learned a lot about the health care industry, hospital care processes, and VTE prevention and treatment. When I look back at the start line, I am so grateful that I selected this topic, and I think it fulfilled part of my childhood dreams.