Clinical Decision Support to Advance Venous Thromboembolism Prevention

Chad Hodge, Amy Rubin, Mark Rimbergas
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**Problem**

**Introduction**

Clinical decision support tools can provide valuable assistance in improving processes within patient care. These tools can provide an impetus to make it easy for the clinician to do the right thing at the right time. Identifying critical areas in which to use these tools is very important. One area within in a hospital environment that can be impacted greatly is on the prevention of venous thromboembolism (VTE). Incorporating a standardized, structured, and reliable protocol via a clinical decision support (CDS) tool will allow for ease of use and a straightforward
approach in tackling this critical issue. Venous thromboembolism lends well to utilization of a tool to assist with risk stratification, appropriate selection of the prevention mechanism and then, as needed, monitoring of the intervention during admissions, transfer in care and discharges as well as with any changes in patient’s clinical status. These tools have been shown to make an impact in patient care. (1)

**Clinical Relevance**

Venous thrombosis is a clot that forms in a vein. The two most serious types of clots that form are deep vein thrombosis (DVT) and pulmonary embolism (PE). Pulmonary embolism is commonly caused as the result of pieces of the clot (embolus) breaking from the clot that begin as a DVT and circulate to the lung and becoming lodged. These types of clots are life threatening. If patient survives, the complications can be extremely severe. In addition, this puts them at a substantially higher risk in the future for another episode of VTE.

DVTs are an extremely prevalent medical problem. The estimated incidence is 80 cases per 100,000 patients. More than 200,000 people develop venous thrombi per year with 50,000 going onto develop a PE. (2) Approximately 1 in 10 of the 2 million patients per year that suffer a DVT will die from a pulmonary embolus. (3) Pulmonary embolism is the most preventable cause of hospital death. (1) However, even though it is the most preventable cause of death and there are substantiated prevention guidelines and mechanisms in place, the incidence is still high. (4) The Agency for Healthcare Research and Quality believes that the prevention of VTE is “the number one patient safety practice.” (3)

Vascular endothelial damage, stasis of blood flow, and hypercoagulability of blood are three etiologic factors that Rudolph Virchow first postulated led to thrombosis. (5) However, over time, it has been recognized that all risk factors “reflect these underlying pathophysiologic processes and that VTE does not usually develop in their absence.” (5) There are many readily identifiable risk factors that place the patient at a greater risk of developing venous thromboembolism. Table 1 below shows the most commonly identified risk factors. The strong risk factors can trigger prophylactic treatment of VTE alone while moderate to weak risk alone would not immediately trigger prophylactic treatment. However, each risk factor and combinations of risk factors should be thoroughly reviewed and taken into consideration when identifying the overall risk of the patient. (5)

<table>
<thead>
<tr>
<th>Risk Factors for Venous Thromboembolism</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Strong risk factors</strong></td>
</tr>
<tr>
<td>Facture (hip or leg)</td>
</tr>
<tr>
<td>Hip or knee replacement</td>
</tr>
<tr>
<td>Major general surgery</td>
</tr>
<tr>
<td>Major trauma</td>
</tr>
<tr>
<td>Spinal cord injury</td>
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</table>
Paralytic stroke
Pregnancy, postpartum
Previous venous thromboembolism
Thrombophilia

Table 1: Risk Factors for Venous Thromboembolism (5)

Utilizing the risk factors for the individual patient, the provider of care needs to make an appropriate assessment on what type of prophylaxis should be chosen for the patient. This should be accomplished during admission, transitions of care, discharges as well as with any changes in patient’s clinical status. Patients are typically identified as low, moderate, or high risk. Based upon the stratification, the provider chooses the most appropriate form of prophylaxis. There are 3 categories of prophylaxis, early and frequent ambulation, pharmacologic agents and mechanical tools. For patients identified as low risk, the primary form of prevention is for early and frequent ambulation. Patients that are categorized as a moderate risk would typically receive pharmacologic agents with or without mechanical methods. Finally, for high risk patients, pharmacological agents in conjunction with mechanical devices are used. (6) Pharmacological mechanisms include unfractionated heparin, low molecular weight heparins, fondaparinux and warfarin. (1) Mechanical prophylaxis includes intermittent pneumatic compression and the less frequently used graduated compression stockings. (6)

In selecting prophylaxis, the provider must also evaluate whether the patient has any potential contraindications to any form of prophylaxis. Potential contraindications to mechanical prevention include leg ischemia, known DVT, previous immobility, and severe arterial insufficiency. Absolute contraindications to pharmacologic treatment include active hemorrhage and severe trauma to head or spinal cord with hemorrhage in the last 4 weeks. Relative contraindications include intracranial hemorrhage within last year, craniotomy within 2 weeks, intraocular surgery within 2 weeks, gastrointestinal, genitourinary hemorrhage within the last month, thrombocytopenia (<50K) or coagulopathy (prothrombin time >18 seconds), end stage liver disease, active intracranial lesions/neoplasm, hypertensive urgency/emergency and post-operative bleeding concerns. (7)

Administrative relevance
Besides the clinical importance of thromboprophylaxis, there are many administrative reasons to implement a CDS tool to further enhance this process. The cost of treating VTE is very high and places a burden on the organization. Cost-effectiveness of the prevention of VTE has repeatedly been demonstrated. (1) The incremental cost associated with a DVT event is estimated to be $10,000 and if development of a PE occurs the cost is estimated at $20,000. (7)

There are many regulatory and other agencies that have goals that tie directly to VTE prevention. The National Quality Forum (NQF) identified VTE prevention as a priority. The Centers for Medicare and Medicaid Services (CMS) have included this goal as voluntary clinical measure that providers can report on and receive bonus payments as a result. Hospitals also have a mandatory reporting regarding the number of patient assessed upon admission and the number of
patients that received prophylaxis based on the assessment. (8) In addition, The Joint Commission has aligned with both NQF and CMS to incorporate VTE prophylaxis into the accreditation process. Also CMS through the EHR incentive program and Meaningful Use included as 6 of the 15 clinical quality measures, the established NQF measures related to VTE. Finally, CMS has designated VTEs following total knee replacement and hip replacement as a “never event” which they consider as preventable, and will not reimburse the hospital for treatment. (9)

**Existing VTE Clinical Decision Support Tools**

There are several clinical decision support tools that have been developed to assist with VTE. The different tools each hit different pieces of the overall system. One tool was a critiquing tool versus a reminding tool but showed promise in changing provider’s actions to improve use of prevention protocol. (10) Another system provided for a passive alert that prompted the provider that the patient was at risk for VTE based on information found through a query of the system at specified periods throughout the day. (11) One tool used the data extracted from the health record to an alert to provider when prevention was needed and allow entry of prophylaxis or to withhold prophylaxis. (12) All tools had a positive effect but did not fully incorporate the process of VTE prophylaxis from start to finish.

**Clinical Goals**

As outlined above, VTE is a potentially disabling and life-threatening condition which is preventable. Also as discussed, attempts have been made to improve outcomes by utilizing clinical decision support tools. The clinical decision support system (CDSS) proposed in the paper and outlined below wants to add another layer to tools currently in use. The tool is more comprehensive than existing tools, incorporates the tool into the provider’s workflow, and is proactive and not reflective. The hope is that this CDS tool can be incorporated into a wide array of existing electronic health records to provide a structure approach to the prevention of VTE. The tool can be modified to align with local policy and procedures. The high-level goals of the project that will be addressed are listed below:

- To incorporate into the existing electronic health record to provide automation of risk stratification.
- To provide automation of the presentation of the preferred prevention mechanism to the end-user.
- To streamline the selection and ordering of the preferred mechanism or selection and ordering of another mechanism with an appropriate reason for selecting a non-preferred mechanism.
- For pharmacologic prevention mechanisms, to incorporate CDS tools to allow for drug-drug, drug-allergy, dosing checks and adjustment based on patient-specific factors.
- For pharmacologic prevention mechanisms, to automate proactive ordering of appropriate lab monitoring.
For non-pharmacologic prevention mechanisms, to automate placement of patient care orders for the nursing staff to carry out at the appropriate time.

- To incorporate this tool seamlessly into the provider’s workflow.
- Finally and most importantly to improve and optimize prevention of VTE events.

**Administrative Goals**
The administrative goals are an important factor to consider as well as the clinical goals. For this CDS tool implementation, the goals are:

- To decrease cost associated with treatment of preventable venous thromboembolic events.
- To meet the various regulatory and quality assurance goals related to thromboprophylaxis.

The model and system design will be discussed below to delineate how this clinical decision support tool will accomplish these goals.

**Model**
During the course of treating a hospitalized patient, several factors that place the patient at risk for a venous thromboembolism can arise. Based on the procedure being performed on the patient, the patient’s Body Mass Index, mobility, length of stay, complications from the procedure and several other factors all conspire to increase the odds a patient will acquire a VTE. By understanding what data is needed to make a decision about the patients risk stratification for a VTE, and even what preventative measures are best for the patients given situation, a clinical decision support rule can give the patient a fighting chance at avoiding a potentially life-threatening condition.

This section aims to clearly define what data elements are needed from an EMR in order to be able to construct a decision support rule based on risk stratification, as well as to be able to present a clinician with preventative options that will decrease a patient’s chance of developing a VTE.

**Model Design Elements**
The model required for this decision support rule can be thought of in three separate pieces. The first piece of the model is what will be used to determine how the hospitalized patient is stratified for which VTE intervention. The second piece describes the data that will be needed to support the execution of that intervention order based on the stratification. The final piece of the model will be used to gather contraindications, so that inappropriate interventions can be discounted, and more effective solutions can bubble to the top of the alert.

For the first piece of the model, deliberate care was given when choosing the necessary fields that will come from the patient’s electronic medical record in support of determining what
stratification the patient falls within to delineate the VTE protocol that is appropriate. Those fields were identified as:

1. Age (unsigned-integer < 130)
2. Body mass index (unsigned integer <50)
3. Had a surgery lasting over 1 hour while admitted to hospital (Boolean)
4. Currently on HRT or oral contraceptives and female (Boolean)
5. Test results indicate hypercoagulability (Boolean)
6. Active cancer (Boolean)
7. Bed rest or otherwise immobile (Boolean).

The second piece of the model is used to capture the clinicians’ responses to the suggested VTE protocol, and also to support the ordering of the intervention, as well as the monitoring and reporting of those results. Those fields are:

1. Alert trigger time (date/time)
2. Alert ignored / cancelled (Boolean)
3. Risk group pre-selected on alert by CDSS (enumeration: Low, Med, High)
4. Pharmacological intervention selected (enumeration: UFH, LMWH, warfarin)
5. Pharmacological intervention dosage (unsigned integer)
6. Pharmacological intervention rate in hours (unsigned integer)
7. Mechanical intervention selected (enumeration: (sequential compression device, leg hose)
8. Mechanical intervention area: (enumeration: left leg, right leg, both) (7)
9. Early and frequent ambulation selected (Boolean)

The third model is used to describe contraindications for potential VTE interventions. This model is perhaps just as important as the intervention itself. By closely monitoring a patient’s contraindications, inappropriate therapies can be avoided that may make the patient’s situation worse. The fields needed to support this model are as follows.

1. Active hemorrhage (Boolean)
2. Severe trauma to head or spinal cord with hemorrhage in the last 4 weeks (Boolean)
3. Intracranial hemorrhage within last year (Boolean)
4. Craniotomy within 2 weeks (Boolean)
5. Intraocular surgery within 2 weeks (Boolean)
6. End stage liver disease (Disease)
7. Thrombocytopenia (<50k) of prothrombin time > 18 seconds) (Boolean)
8. Hypertensive emergency (Boolean)
9. Allergic to warfarin (Boolean, and severity)
10. Allergic to un-fractionated heparin (UFH) (Boolean, severity)
11. Allergic to low molecular weight heparin (LMWH) (Boolean, severity)
12. Critical drug-drug interactions (Boolean, severity)
13. Has skin lesions on left leg (Boolean)
14. Has skin lesions on right leg (Boolean) (7)

Clinical Workflow

The above figure depicts a typical workflow that a hospitalized patient may go through. The first opportunity to assess VTE risk is immediately after the patient has been admitted to the hospital. Several fields will already be available, and a preliminary risk assessment can be obtained. The second opportunity to determine if a patient is at risk for VTE is during normal actions taken on the patient while admitted. For example, labs may be ordered, procedures performed, nursing documentation completed, and observations noted. All these activities generate data. That data will be used to reevaluate the patient’s VTE risk on either a nightly basis, or during the clinicians workflow, such as when ordering medications, or otherwise reviewing the patient’s chart. This should also be accomplished during any transitions of care. The final opportunity to determine if the patient is at risk for VTE is at discharge. If the patient is at continued risk upon discharge, then supporting medications can be prescribed, and sent home with the patient, along with some basic education on what the patient should look for.
### Modeling Technique

#### Logic

<table>
<thead>
<tr>
<th>Rule Category</th>
<th>VTE Intervention protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rule Title</td>
<td>Stratify the patient’s level of VTE risk and prompt clinicians to intervene.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Risk Group Definition</th>
<th>VTE Intervention protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age &gt;= 70</strong> (demographic data);</td>
<td><strong>Stratify the patient’s level of VTE risk and prompt clinicians to intervene.</strong></td>
</tr>
<tr>
<td><strong>Obese</strong> (the weight in kilograms divided by the square of the height in meters) &gt;= 30 OR ICD9 code of 278.0;</td>
<td></td>
</tr>
<tr>
<td><strong>Bed Rest or Immobility</strong> (found through Natural Language Processing (NLP) of nursing documentation);</td>
<td></td>
</tr>
<tr>
<td><strong>Female Hormone Replacement Therapy or oral contraceptives</strong> (found on active medication list);</td>
<td></td>
</tr>
<tr>
<td><strong>Major Surgery</strong> (any surgery lasting over 1 hour);</td>
<td></td>
</tr>
<tr>
<td><strong>Active Cancer</strong> (ICD9 149.0 to 172.99, 174.0 to 209.9) (12);</td>
<td></td>
</tr>
<tr>
<td><strong>Prior VTE</strong> (ICD9 415.1, 415.19, 453.8, 453.9, and 671.31 to 671.50) (12);</td>
<td></td>
</tr>
<tr>
<td><strong>Hypercoagulability</strong> (presence of factor V Leiden, lupus anticoagulant, and anticardiolipin antibodies) (12); (13) (14)</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Trigger Condition</th>
<th>VTE Intervention protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Admission of Hospitalized patient;</strong></td>
<td><strong>Stratify the patient’s level of VTE risk and prompt clinicians to intervene.</strong></td>
</tr>
<tr>
<td><strong>During normal activities of patients stay (time and data driven);</strong></td>
<td></td>
</tr>
<tr>
<td><strong>During discharge;</strong></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Displayed Message</th>
<th>VTE Intervention protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>This patient has been identified as having a risk for venous thromboembolism (VTE). Based on his recent medical/surgical history, his risk level is (LOW</td>
<td>MED</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Coded Responses</th>
<th>VTE Intervention protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Order early and frequent ambulation</td>
<td><strong>Stratify the patient’s level of VTE risk and prompt clinicians to intervene.</strong></td>
</tr>
<tr>
<td>B. Order suggested pharmacological intervention;</td>
<td></td>
</tr>
<tr>
<td>C. Order suggested mechanical intervention;</td>
<td></td>
</tr>
<tr>
<td>D. Acknowledge alert, but take no action; (Reason Required )</td>
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</tr>
</tbody>
</table>

Now that it is clear what data elements our intervention needs to track, we can determine how we can come across the needed data to fill the model. For this intervention, we will need to make use of both a time driven CDS rule, as well as a data driven CDS rule. You can see Figure 1 - VTE intervention workflow (2) for a visual depiction of when each is needed. For the time driven portion, each night the patient’s medical record will be scanned to get answers to each question posed by the model listed above. Demographic information can answer the age question. More advanced means will be needed to answer questions like hypercoagulability. Each night, lab results for the patient can be scanned looking for results that suggest such a condition, such as presence of factor V Leiden, lupus anticoagulant, and anticardiolipin antibodies (12). That conclusion can be stored so the rule can use it as needed since the rule will not just trigger at the end of each day, but during workflow actions as well. Similar steps are taken to calculate Body Mass Index (BMI), where the most recent weight and height are obtained from nursing observations stored in the Electronic Medical Record (EMR), and a BMI score can then be calculated. If observations of height and weight are not present, an International Classification of Diseases, 9th Revision, Clinical Modification(ICD9) code can also be sought out on the
patient’s problem list of 278.0 (12). Previous VTE (ICD9 415.1, 415.19, 453.8, 453.9, and 671.31 to 671.50) (12), cancer (ICD9 149.0 to 172.99, 174.0 to 209.9) (12), surgeries, and HRT (had by scanning patient’s active medication list) can all be gained by identifying appropriate codes in the patients chart, preferably in the problem list, or active medication list. Bed rest or immobility can be found by scanning nursing documentation with some form of Natural Language Processing (NLP). A similar methodology will be employed to fill in the contra-indication model.

Once VTE has been identified, a problem can be added to the patient’s master problem list as “VTE, Risk for”. That way an alert is not required for the clinician to be constantly reminded of the risk status of the patient, but also so that the CDS alert itself can know when to stop alerting clinicians to the patient’s risk of VTE. Alternatively, if an item is not added to the problem list, a scan of orders can reveal if any of the prophylaxis has been ordered, such as heparin, warfarin, compression hose, and the like. If so, then the alert does not need to continue.

Knowledge Engineering
The design of the CDS rule in this paper has relied on several different technologies, and terminologies. Nursing documentation will be scanned using NLP for appropriate phrases, problem lists will be scanned for ICD9 codes, and calculations will be performed to determine BMI. These concepts are represented in fragile and ever changing nomenclature. The codes may change for what a VTE means in ICD9, or what an intracranial hemorrhage is. Not only is it likely that these codes will change over time, but an organization may move to a new code system altogether, such as ICD10. Refinement to the rule may also need to take place in order to improve the incidence, sensitivity, and specificity of the VTE intervention described here. All these shifts will require our rule to be rewritten and constantly validated unless a more robust solution can be found. Luckily, one exists. By using a knowledge repository, semantic shifts can be accounted for, logic can be altered, and code systems can be changed, all while maintaining the integrity of our VTE protocol, as well as allowing for layering of VTE protocols.

Acquisition
The knowledge for this system is coming from discrete elements scattered throughout the patient’s electronic medical record, as well as through NLP scanned documents, and laboratory results. Storing these results in the above described models within a knowledge repository allows us to acquire and store the CDS rule and its constituent elements in a central location. By storing that data in the knowledge repository, we are able to store the clinician’s choices, and other analytic data in the same repository. This will allow for reports, prevalence, incidence, sensitivity, and specificity of this protocol to be managed and assessed from a central location.

Maintenance
As our intervention for VTE is placed into the departments throughout our organization, feedback will come from each department as to how the rule can be made more effective, or how it can be customized to meet their needs. For example, OB/GYN may have its own contra-
indications for VTE, or cardiology may have more stringent rules for when VTE should be indicated. By using a knowledge repository, we will be able to layer interventions. This means that a base rule can be defined for all of the departments as a whole. Then each department’s specific criteria that need to supersede the base rule can be layered on top of the base rule. Administration and management of all of these rules can be done easily through common KR tools.

By storing our rules and models in a KR, as new standards come available for identifying or treating VTE, such as a “gold standard”, or newly published information, rules can be modified easily, and pushed to all systems that use the rules.

The System
As stated in the introduction, the goal of this project is to create a CDSS to assist with risk stratification, appropriate selection of the prevention mechanism and then, as needed, monitoring of the intervention for potential VTEs. In this portion of the paper the components, the architecture, the inputs/outputs, workflow fit, and the interfaces required to achieve the goal aforementioned will be discussed.

Components

Active Integrated NLP-CDS inference engine
To achieve the requirements mentioned in the model portion of this paper it was determined that using an active integrated NLP-CDS inference engine would be the best fit. An active NLP CDS includes alerting, monitoring, coding, and reminding (15). Like a passive system, an active system can process a variety of textual sources, such as clinical records, biomedical literature, web pages, and suicide notes (15).

This NLP system will be governed by and will be in support of the CDSS. The NLP is comprised of a suite of modules that can be selected from and aligned into a pipeline that is customizable for a variety of tasks including risk stratification (Figure 2). In this architecture, the CDS system drives and monitors the tightly integrated set of NLP modules and ensures application-specific workflow (15).

Active Integrated NLP-CDS Modules:
1. A module that monitors the EHR for insertion of new data.
2. A module for text and supplementary data retrieval.
3. A module for lexical, syntactic, and semantic processing.
4. A module with decision rules.
5. A module for output generation.
7. A module for output delivery.
Analysis and Data Mining Module
This module helps analyze and mine data with the intention of augmenting the clinical knowledge database.

Knowledge Base or Data Warehouse
The knowledge base is a database that holds current clinical knowledge base including clinical terminologies and data dictionaries.

Knowledge Base Interface
This interface will be used to add new information and allow only authorized users to manipulate the knowledge database.

The EMR
The EMR system will be used to capture, organize, and deliver patient medical information and serve as a longitudinal clinical patient database.

The End User Interface
Clinicians will be able to access and add new patient information in the EMR through the use of workstations, tablets, and other mobile devices that have been securely set up in the network. In addition, data can be received from other modalities such as medical devices.

Architecture
Description
In this CDSS architecture an active integrated NLP-CDS inference engine will be used as a module integrated directly in the EHR. This NLP system will be governed by and will be in support of the CDSS. The NLP is comprised of a suite of modules that can be selected from and aligned into a pipeline that is customizable for a variety of tasks including risk stratification (Figure 2). In this architecture, the CDS system drives and monitors the tightly integrated set of NLP modules and ensures application-specific workflow (15). This NLP system is provided with information about the tasks and can potentially take over the management of the process. For example, the NLP may get a signal and text for performing a certain task from the CDS system, to perform the task independently, and deliver the pre-specified output to the decision support module, which then incorporates the results into an EHR (Figure 2).

High Level Process Flow
The system will be activated either on a timed frequency, or from data being entered into the EHR. As data is received in the EHR, the integrated system will monitor the incoming reports and start tasks as needed (Figure 2). The data is scrubbed for syntactic and other errors in another module which accesses the knowledge base to verify clinical terminologies, data dictionaries, and other current standards (16). When the system has verified the information, the data is sent to the decision rule module were predefined algorithms will calculate potential hazards and treatment options. After this stage, the output generation and delivery rules modules
will be triggered and will then tell the output delivery module to transmit the display message to the end user (Figure 3). This cycle of monitoring will continue throughout the patient’s intervention and the system will continue to send the end users messages if there may be a need for VTE prophylaxis.

Standards Used

1. **HL7**: Will be used for the exchange, integration, sharing, and retrieval of electronic health data.
2. **XML**: Will be used for document storage and data integration.
3. **CDA**: For specifying encoding, structure, and semantics of clinical documents for exchange.
4. **LOINC**: For identifying medical laboratory observations.
5. **SNOMED**: To help index, store, retrieve, and aggregate the data.
6. **CCOW**: To enable the disparate applications in our organization to synchronize in real-time.
7. **HIPPA**: To ensure patient confidentiality when patients are transferred to other healthcare providers and hospitals.
8. **ICD-9**: To classify diseases, injuries, and cause of death.
Inputs
Inputs into the system obviously will include patient history, changes in conditions, and addition of new prescribed medications. However, CDS involves more than patient-specific information from the clinical record. Inputs to consider also include general medical knowledge regarding best practices in diagnosing or treating conditions experienced by the patient, and actionable recommendations offered in free text in publicly available online databases (such as MEDLINE/PubMed, BioMed Central, and PubMedCentral) that provide access to scientific literature (15).

Outputs
Below is an example of how the output given by the CDS system to the provider for guidance may appear. The provider at any point can override the guidance by providing justification.

![VTE ALERT - HIGH]

**Recommend:**

Factor Xa Inhibitor (Fondaparinux) combined with GCS

**Rationale:**

Patient with history of heparin induced thrombocytopenia, platelet count < 50,000, and history of coagulopathy.

[Click to Order] [Click to Change Order]

**Figure 3: Guidance**

**Workflow fit**
As stated earlier, the system in Figure X-knowledge representation will have a module that monitors an EHR for insertion of new data into the specific fields identified in the model. When a new patient is admitted to a hospital and is entered into the EHR, the NLP system could activate the basic processing pipeline to determine whether or not the patient is a candidate for the VTE intervention or not. Processing the following impression section: Age >= 70 (demographic data); Obese (the weight in kilograms divided by the square of the height in meters) >= 30) OR ICD9 code of 278.0; Bed Rest or Immobility (found through NLP of
nursing documentation); **Female Hormone Replacement Therapy or oral contraceptives** (found on active medication list); **Major Surgery** (any surgery lasting over 1 hour); **Active Cancer** (ICD9 149.0 to 172.99, 174.0 to 209.9) (12); **Prior VTE** (ICD9 415.1, 415.19, 453.8, 453.9, and 671.31 to 671.50) (12); **Hypercoagulability** (presence of factor V Leiden, lupus anticoagulant, and anticardiolipin antibodies) (12); the system will extract information about potential VTE. The system will look up decision rules for potential VTE that might, for example, contain instructions to retrieve the structured results of blood tests and look for any contraindication. If the indications add up, a reminder message will be generated by the system to say that the patient is more likely to have a VTE. The system could use the results of the text analysis to solicit more information (for example, find evidence for best approaches to prophylaxis management) and present succinct summaries of the information (15). At this point, depending on preferences, the NLP system can hand off the reminder text and summaries to the CDS system and the CDS system will provide guidance directly to the provider (15). This cycle of reviewing new data (including new ICD-9 codes) and risk stratification will continue throughout the intervention.

**Interfaces**

All the interfaces in this system will be handled by an interface engine in order to transform or map the data being sent to meet a recipient applications requirement while a message is in transit so that it can be accepted by the receiving application.

Interfaces include connecting to the emergency room, hospital information system, Pharmacy, portable devices, and other parties involved in the care of the patient.

In addition, interfacing with outside software systems should also be considered. Systems “such as the National Library of Medicine’s Unified Medical Language System (UMLS), developed to facilitate clinical data processing and linking to biomedical knowledge, General Architecture for Text Engineering (GATE), systems based on the Unstructured Information Management applications (UIMA) and provided by the Open Health Natural Language Processing (OHNLP) Consortium, and LingPipe can be used in this type of customizable NLP-CDS system coupling.” (15)

**Implementation, Evaluation, and Challenges**

This clinical decision support tool would be fully and thoroughly tested prior to implementation within any organization. Once tested in a theoretical setting, the tool should be tested with a small group of providers. This group would provide feedback into the functionality and usability of the tool. The changes would be incorporated into the tool and then re-tested for improvement. Utilizing small cycles of Plan, Do, Study and Act (PDSA), this can be easily accomplished. Once the tool has been approved by the group, the CDS can be spread to other groups of providers. Within each group, PDSA cycles can be continued to be utilized to optimize the tool. Protocols
for the PDSA process and the change management process as the result of the PDSA would be clearly delineated.

Challenges surrounding this tool can arise in any area; however, anticipation of these challenges can ease the burden created. First, the triggering of the stratification tool could be limited if the proper data is not elucidated during the intake of the patient or if historical data that is in the patient record is not complete. By carefully delineating these anticipated deficiencies, the effects can be minimized. Currently, there is no universally accepted stratification method for VTE. Allowing flexibility in the model based upon organizational preferences can assist in acceptance. Another challenge could be resistance by providers to implement the tool. By educating the providers and including them in the process of implementation and improvement, the buy-in can be increased. This could also assist in alleviating another challenge and that is usability. By gathering input during the early implementation phase, usability and incorporation into the provider’s workflow can be dramatically improved.
Works Cited


