Use of Six Sigma to Improve the Safety and Efficacy of Acute Anticoagulation with Heparin

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The recent Institute of Medicine report, *Crossing the Quality Chasm: A New Health System for the 21st Century* [1], highlighted the need to improve the reliability of basic processes in health care. One way in which health care has addressed this need is through the implementation of continuous quality improvement techniques. Six Sigma is a process improvement approach widely adopted in industry [2] that is beginning to be used to improve quality of care and patient safety in health care organizations [3–5]. Originally developed by Motorola in the 1980s, Six Sigma is a methodology that helps organizations focus on developing and delivering near-perfect products and services.

Six Sigma uses the DMAIC approach: Define, Measure, Analyze, Improve, and Control (**Table 1**). There is a strong focus on customer expectations. Six Sigma holds that the customer experience (called the "Y") is the result of process factors (called the "Xs"). In traditional process improvement approaches, process results are measured, but the drivers of these results may not be carefully examined. In Six Sigma, statistical analysis is used to relate process drivers to the customer experience. Effective change requires that the Xs be accurately measured, their causes identified, and the process modified so that the customer expectations are almost always met. This article describes the use of Six Sigma to improve acute anticoagulation services in a community hospital.

The Six Sigma Heparin Project

Virtua Health is a not-for-profit, 4–community hospital health care system in southern New Jersey. Memorial Hospital, one of the 4 Virtua hospitals, is a 292-bed acute care facility located in Mount Holly, New Jersey. The medical staff is made up of voluntary, community-based physicians.

Virtua Health adopted Six Sigma in October 2000 as a tool for improving processes to achieve operational goals. Six full-time project leaders, known as Six Sigma Black Belts, were trained by Six Sigma consultants from General Electric Medical Systems (GEMS). Virtua senior management in consultation with GEMS trainers chartered 6 initial projects, which ran between January and June 2001. The anticoagulation project, which began in June, was the first clinical process improvement Six Sigma project at Virtua. The anticoagulation team, made up of frontline staff members, was led by a Black Belt with ongoing support provided by GEMS staff as needed.

Project Selection

Scoping, or determining the right operational area for a project, is the preliminary step in the DMAIC process. The project chosen should be important to the organization, have a source of data, be large enough to provide meaningful improvement, and yet be focused enough such that results can be achieved in 4 to 6 months.

Heparin is an anticoagulant widely used for the treatment and prevention of thromboembolic disease. Heparin therapy is generally monitored by measurement of the activated partial thromboplastin time (aPTT). It has been shown that in patients presenting with thromboembolic disease, achieving a therapeutic aPTT within the first 24 hours of therapy is associated with a reduction in recurrent thromboembolism [6]. The most important risks of heparin therapy are serious bleeding and heparin-induced thrombocytopenia (HIT). Safe and effective use of heparin requires that the occurrence of such adverse events be minimized and, when they do occur, that they be detected and addressed promptly. Memorial Hospital had been using a weight-based protocol for heparin administration since 1995. The weight-based protocol had been implemented because of concerns about the variation in dosing adjustment practice from physician to physician, the delay incurred by trying to reach a physician for each dosage adjustment, and the demonstrated superior process outcomes achieved with a protocol-driven adjustment approach [6]. However, the use of heparin remained worrisome.

The hospital used quality assurance strategies to monitor heparin use. Medication errors involving heparin were reported to the pharmacy and quality assurance departments. Errors included occasional episodes of incorrect pump settings, incorrect use of pumps, delays in obtaining and reacting to aPTTs, bolus dosing errors, and mixing errors of heparin infusions. Errors occurred infrequently, and most

From Virtua Health, Marlton, NJ.

Table 1. DMAIC Process

Define	What is the right process result to address? What does the customer expect?
Measure	How is the current process performing?
Analyze	What are the most important factors driving the process results? What changes will deliver the desired process result?
Improve	How well did the changes improve the process?
Control	What measurements will the process owner use to confirm sustained improvements? What system and structure changes support sustained gains?

were discovered before any patient harm occurred. Serious adverse events were reviewed in detail using the root-cause analysis methodology.

Existing quality improvement methods, including root-cause analysis, provided information and led to incremental improvements in specific steps that had failed. They did not address the overall performance of the anticoagulation process in quantitative terms. The quality assurance department only reviewed cases that were reported by incident report or that otherwise raised quality concerns. The organization had no ongoing mechanism to comprehensively evaluate and monitor the day-to-day performance of the weight-based protocol. Several factors contributed to this. The process is interdisciplinary and ownership is diffuse. Data from laboratory and pharmacy had not been effectively linked to quantify the number of patients on heparin or report measures of the effectiveness of the medication beyond individual patient results. Further, the existing approaches were not well adapted to mistake-proof steps that failed very rarely but that could have serious impact, such as grossly incorrect pump settings.

Define Phase

During the define phase, the team identifies the process requirements and customer deliverables. In Six Sigma methodology, the customer's perspective is key, and the customer is an authoritative reference for process specifications. (Although the term "customer" is controversial when used in the context of health care, the term is used in this article with reservations understood.) Accurate customer identification is necessary in this phase. The team identified patients and physicians as the customers of acute anticoagulation services.

The process specifications for both customers were safe and effective acute anticoagulation capability. The team used the performance of the weight-based heparin protocol reported by Raschke [6] as the process performance standards for effectiveness of anticoagulation. Raschke reported that among patients randomized to a weight-based protocol (starting dose, 80 U/kg body weight bolus, 18 U/kg per hour infusion), 86% achieved an aPTT that exceeded the therapeutic threshold 6 hours after the initial bolus dose, and 89% were within the therapeutic range at 24 hours. Preventing or addressing anemia and thrombocytopenia were the process requirements for safety of anticoagulation. The screening criteria for new anemia was defined by the team as drop in hemoglobin of at least 2 g/dL at a rate of at least 1 g/dL per day, with a final value of less than 12 g/dL. Acceptable practice was defined as the drop being noted and appropriate action taken by the physician. The screening criteria for thrombocytopenia was defined as either a 50% drop from the peak platelet count or any platelet count less than 100,000. An acceptable response was defined as recognition of the low platelet count by the physician and appropriate action being taken. This could include discontinuing the heparin or continuing the heparin with an indication that in the opinion of the physician the declining platelet count was unrelated to heparin administration.

Table 2 shows the 5 process results (the 5 Ys) that the team defined as the goals of the project.

Measure Phase

The product of the measure phase is a quantitative, statistical description of current process performance. This requires the identification of the data source, data collection, validation of the accuracy of the data, analysis of the data, creation of a detailed process map, and measurement of current system performance compared with the target level of performance expected by customers. The team used pharmacy and laboratory databases and manual data collection to measure current performance.

Pharmacy data identified 815 patients who had received therapeutic doses of heparin between 1 January and 15 June 2001. Less than half of all aPTTs in these patients were in the therapeutic range; 18% were subtherapeutic and 35% were supratherapeutic. The team randomly selected 36 charts for detailed review to determine how well the automated pharmacy report identified the patients in whom they were interested (ie, those on the weight-based heparin protocol) and the range and frequency of diagnoses in these patients. On review, 6 patients were found to have been on fixed-dose heparin (postoperative vascular surgery, thrombolytic therapy for acute myocardial infarction). In the 30 patients who were receiving weight-based heparin, the following indications were noted: acute coronary syndrome (16), atrial fibrillation (5), prosthetic valves with chronic anticoagulation (3), other outpatient chronic anticoagulation (1), peripheral vascular disease (2), deep venous thrombosis with or without pulmonary embolism (3).

The team constructed a high-level process map (**Figure 1**) to better understand the flow of activities involved in administering and monitoring heparin. Several intervals in the dosing and monitoring cycle were examined. For example, **Figure 2** shows the time intervals between the collection of

Table 2. Targets and Initial Performance of Weight-Based Heparin Protocol

	Target	Beginning Mean Value (n = 26)	Beginning SD
First aPTT after bolus is above therapeutic threshold	> 86%	97%	NA
aPTT in therapeutic range at 24 hr	> 89%	80%	NA
Interval between aPTTs until 2 consecutive are in range	6 hr	8.5 hr	2.1 hr
Low platelet counts noted and addressed	99(+)%	99.86%	NA
Low hemoglobins noted and addressed	99(+)%	99.86%	NA

aPTT = activated partial thromboplastin time; NA = not applicable; SD = standard deviation.

first and second aPTT samples for the 30 patients whose charts were reviewed in detail. The team expected this time to be 6 hours, the standard interval used in heparin monitoring. Four patients had heparin discontinued before the second aPTT was drawn. The mean time for the remaining 26 patients was 8.5 hours. The team felt that this was an acceptable mean since time for collection and processing had not been accounted for in their original setting of the specification of 6 hours. However, although the mean was acceptable, there was a great deal of variation, with some samples being drawn early (which could lead to adjustments based on non–steady state results) while others were drawn quite late (which delayed the time of adjustment of the infusion rate). It appeared that variation was a greater problem than the average performance of this part of the process.

Based on the results of detailed review of the sample charts, the team refined the automated report to exclude patients receiving thrombolytic therapy. The new automated sample included 731 patients.

Of the 731 patients undergoing therapeutic heparin treatment between 1 January and 15 June, 49 were identified by laboratory-pharmacy data as possibly having developed anemia while on heparin. Of these, 18 charts were selected at random and manually reviewed. Major bleeding episodes were defined as retroperitoneal bleeding, intracranial bleeding, bleeding into a prosthetic joint, or overt bleeding that resulted in a hemoglobin drop of 2 g/dL or that required transfusion. Two patients developed their anemia related to a major bleed while on heparin. Both had been identified by the quality improvement system. This resulted in an estimated bleed rate of 0.68%. Critical care nurses and hospitalist physicians asked to estimate the frequency of major bleeds in patients receiving therapeutic heparin offered a similar rate. This rate is lower than that reported in the literature (1.1% to 2.3%) [7]. It is possible that some serious bleeding episodes were missed by both the lab-pharmacy data system and the incident reporting system.

Of 731 patients, 2 had platelet counts of less than 50,000. Both had been identified and properly managed well before the platelets reached this level. No symptoms of overt HIT were noted in either of these 2 charts. When the liberal definition of the 50% drop in platelet count from the highest preceding value was used, of 731 patients, 3 met the definition and 1 patient was continued on therapy after reaching the definition threshold. This was a patient with a final platelet count of 120,000 who had dropped from an initial count of over 250,000. The 120,000 platelet count occurred on the day of discharge and was not noted prior to the patient leaving the hospital. No symptoms of HIT were noted in the record.

The measure phase established the performance of the current system. The team learned that the process usually worked well and mean cycle times were close to specification. There was variation around the means; this was investigated further in the analyze phase.

Analyze Phase

The result of the analyze phase is the identification of the factors that drive the process results. The team constructed a detailed process map (**Figure 3**) that identified all of the steps required to execute the weight-based heparin protocol, from the time the protocol is ordered through the first protocol-driven adjustment. Using the map, the team examined barriers to the successful completion of the process steps. The map revealed that the process, including laboratory and pharmacy sub-cycles, required 92 steps to reach completion of the first dose adjustment. Many of the steps relied on flawless performance by a single individual, usually the patient's nurse. Most of these steps provided no prompt for the next step but rather required the person responsible to remember to act, often hours after the triggering event. In addition, inconsistent interpretations of the protocol requirements were revealed as the team members discussed the process map and shared it with members of the medical, nursing, pharmacy, and lab staffs. The team concluded that the complexity of the system was hampering staff performance and that there were few system elements in place to help staff prevent errors.

Review of the process map revealed several opportunities for process variation and failure around obtaining and

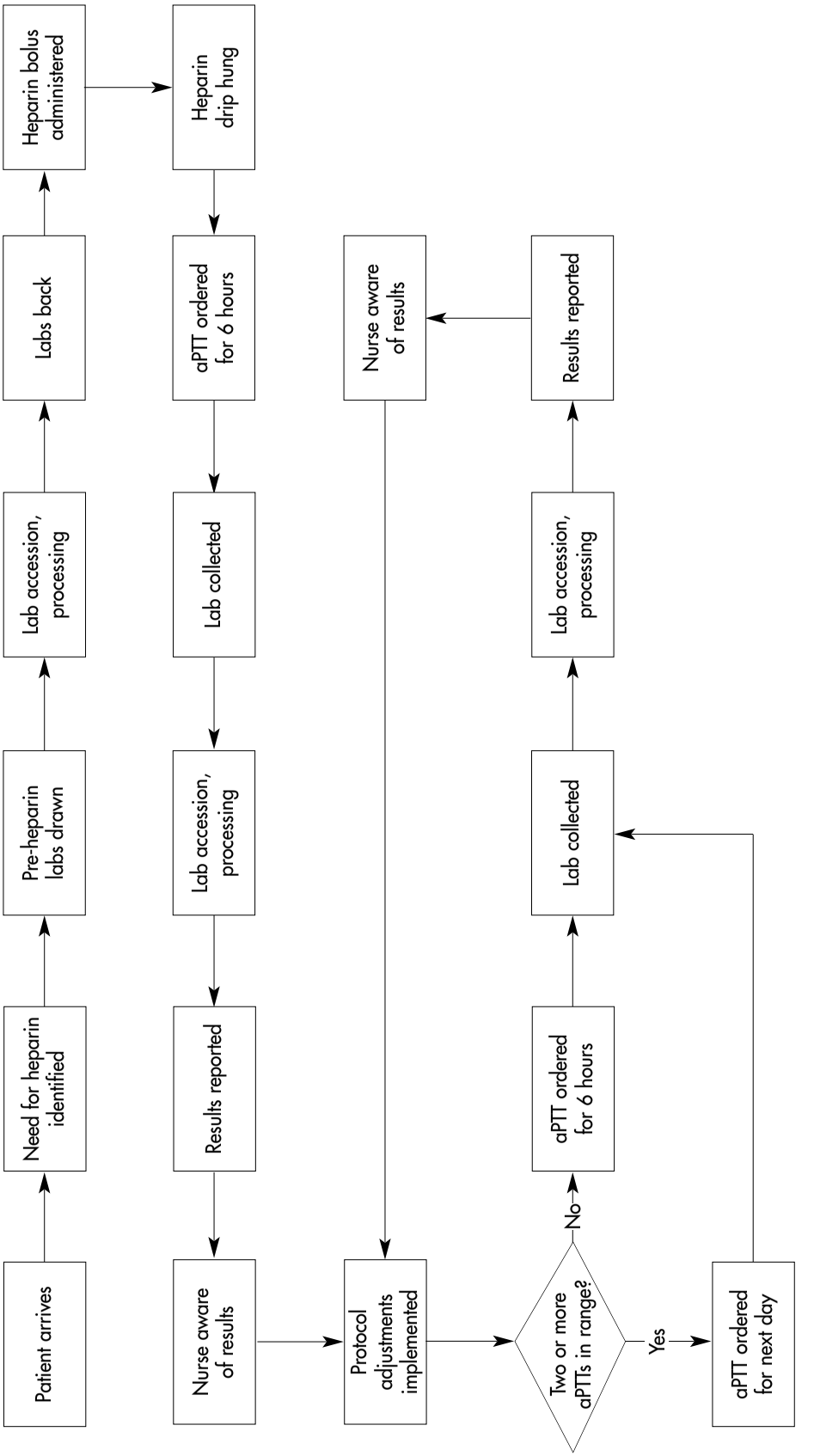

Figure 1. High-level process map for weight-based heparin protocol. aPTT = activated partial thromboplastin time.

reviewing an aPTT. For example, the meaning of "6 hours" was interpreted differently by different members of the team. In the case of an aPTT of 240 or greater, the protocol requires holding the drip for 1 hour then restarting it at 3 U/kg per hour lower. Some team members interpreted 6 hours as beginning at the time the drip was held, while others viewed it as 6 hours after the drip was restarted at the reduced rate.

The availability of an accurate body weight is essential to the use of the weight-based protocol. However, discussions of the process map revealed that many patients were not being weighed. Team members from the nursing department recognized this as a long-standing problem, often attributed to lack of equipment or staff. Data gathered by the team showed that only 48% of patients were weighed on admission. Estimated weights were off by more than 10% in 12 of 42 patients examined.

Although the weight-based protocol functions with little physician input, there are points at which physician involvement is required, such as when a third consecutive aPTT is greater than 240. It was unclear which physician should be contacted. A primary care physician might have ordered the heparin, a cardiologist might have consulted, and a critical care physician group might also have been involved. The nurse was left to decide which physician to call. In some cases, different groups were called for sequential critical results on the same patient. This led to poor communication and increased process variability.

In addition, nursing documentation of lab results and infusion adjustments made was very inconsistent. Documentation was recorded variously in the nursing notes, the nursing flow chart, the medication administration record, and on the heparin order sheet. Documentation was inconsistent even within an individual patient's chart, leading to delay and miscommunication.

Another area of inconsistency was the approach to obtaining and reviewing laboratory studies at the time the weight-based protocol was initiated. Practice varied about whether to hold the initial bolus until the initial labs were reviewed. Physician opinion varied along specialty lines and depended on the perception of the urgency of starting the heparin. Nursing opinion seemed to vary less systematically and was inconsistent even within individual nursing units. The lack of a standard procedure for reviewing initial lab results led to variation in the process.

The process map also identified the potential for failures due to inattention or distraction. For example, the system offers no prompt to remind a nurse to obtain the results of an aPTT that was drawn 6 to 8 hours earlier. This test will only be checked if the nurse remembers that the results are due. With the challenging nursing workload, expecting flawless performance of an unprompted task seems unrealistic. Delays in checking aPTTs were noted but did not contribute to adverse outcomes in this analysis.

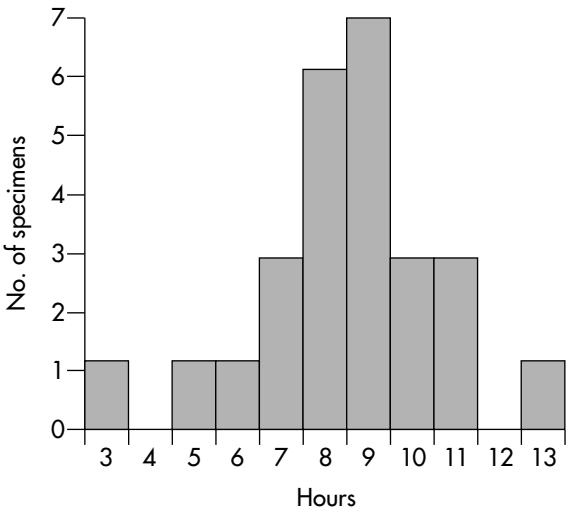

Figure 2. Time from first activated partial thromboplastin time (aPTT) collection to second aPTT collection based on chart review for 26 patients.

Important lessons were also learned by reviewing cases in which the weight-based protocol failed seriously. Most errors were gross deviations from protocol and occurred when heparin was started or were related to the use of infusion pumps. One incident revealed a serious breakdown in communication. None of the incidents were related to delays in obtaining laboratory work, processing the results, or the time to adjust the infusion. There was little opportunity to improve the process by improving cycle time elements.

In summary, the analyze phase revealed a complex process that relied on flawless performance by individuals to achieve the desired outcomes. Many inconsistencies were found in the way heparin was administered, but adverse outcomes were not associated with minor process variation. Rather, they were associated with uncommon, major breakdowns in the delivery of the protocol. Moving process cycle times closer to ideal specifications was unlikely to improve patient safety. The team determined that the greatest opportunity for increasing the safety of acute anticoagulation was by simplifying the process where possible and by error-proofing steps in the current process.

Improve Phase

The product of the improve phase is the implementation and measurement of changes to the process that drive the system toward desired performance. Many opportunities for improvement were identified and interventions implemented (**Table 3**).

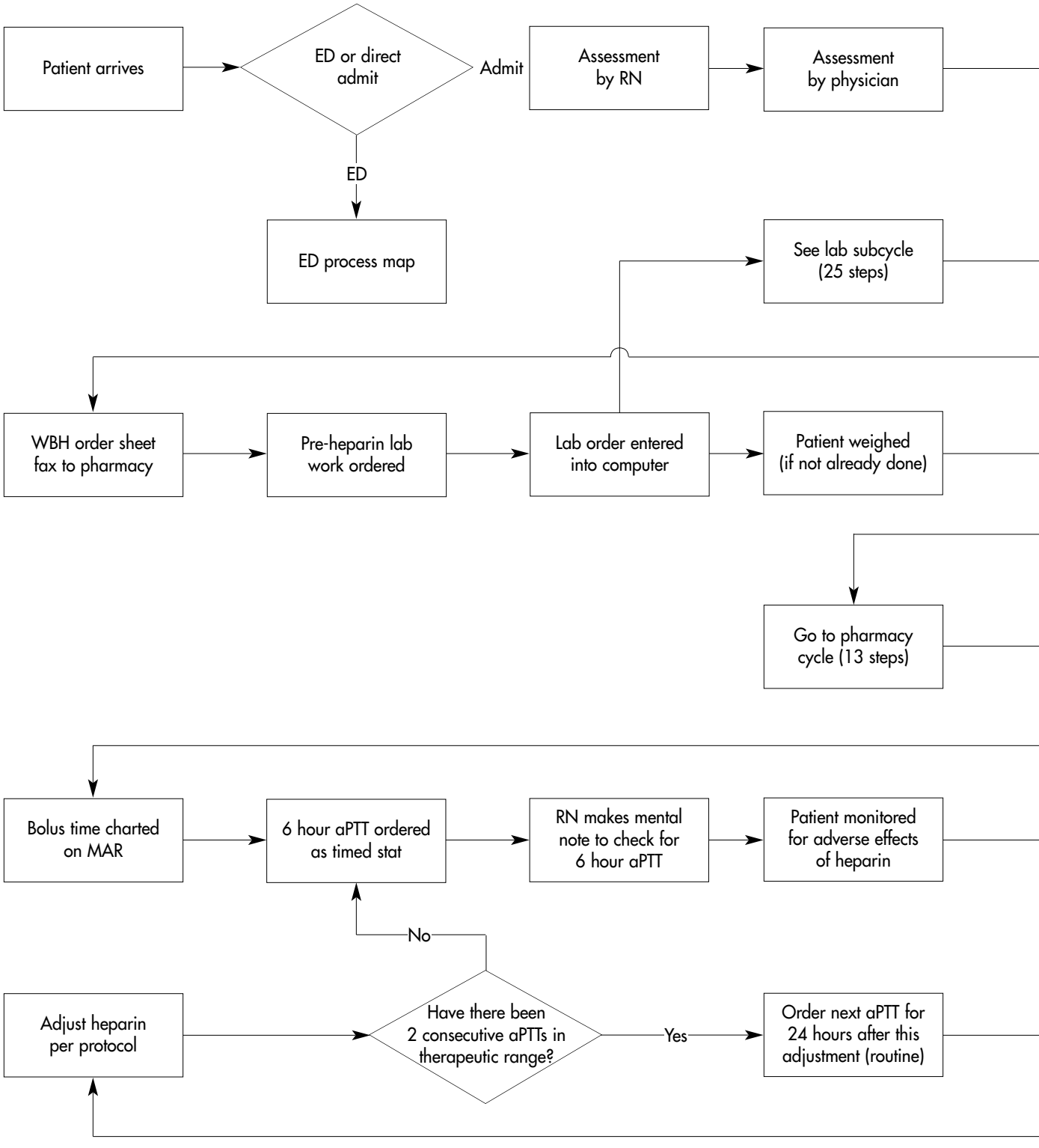

Figure 3. Detailed process map of weight-based heparin protocol. aPTT = activated partial thromboplastin time; ED = emergency department; MAR = medication administration record; RN = registered nurse; WBH = weight-based heparin.

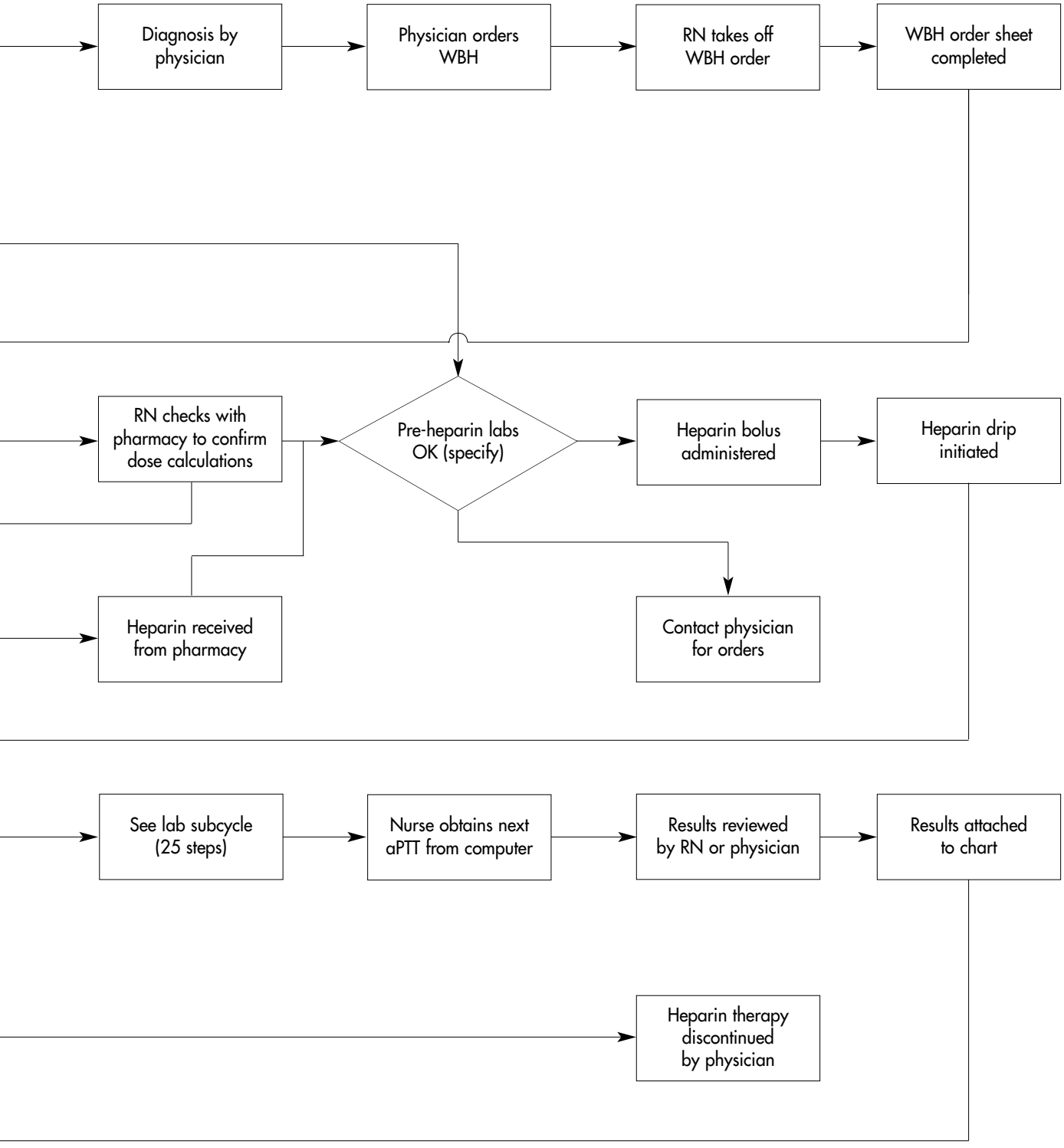
Diagnosis by physician
Physician orders WBH
RN takes off WBH order
WBH order sheet completed
RN checks with pharmacy to confirm dose calculations
Pre-heparin labs OK (specify)
Heparin bolus administered
Heparin drip initiated
Heparin received from pharmacy
Contact physician for orders
See lab subcycle (25 steps)
Nurse obtains next aPTT from computer
Results reviewed by RN or physician
Results attached to chart
Heparin therapy discontinued by physician

Table 3. Weight-Based Heparin Process Improvements

Process Step	Deficiency	Intervention	Anticipated Benefit
Weighing patients	Done on admission only 48% of the time	Bed scales purchased	Easier to weigh patients
Lab-pharmacy data link	No prior system to monitor efficacy of anticoagulation	All patients on therapeutic heparin included in automated review with manual chart review on charts that fall out	Detection of otherwise silent process failures; ongoing comparison to target performance
Heparin hold for aPTT > 240 sec	Unclear definition of start time for 6-hr interval	Clarification with physicians	Decreased process variation
Physician called for aPTT > 240 x 3	Unclear which physician group to call	Identification of physician group responsible for heparin orders on initial order sheet	Decreased miscommunication
Pre-heparin lab studies	Inconsistency among nurses and physicians as to whether to hold heparin until results received	Clarification with physicians. Default is do not wait for labs, with hold option at physician's discretion.	Decreased variation in nursing practice
Infusion pumps	Occasional incorrect setting leading to dosage error	Programmable pumps with drug personalities and maximum drip rate settings	Avoidance of extreme overdosage due to pump setting errors
Use of unfractionated heparin	Complex process with occasional complexity-related failures	Substitute low-molecular-weight heparin	Fewer complexity-related errors

aPTT = activated partial thromboplastin time.

The finding that only 48% of patients were weighed on admission was startling to the team and to leadership. When weighing practices were analyzed, the team found that nursing units with scales integrated into the beds were far more successful at routinely weighing patients. In response to this finding, nursing leadership converted a budget request for several very expensive air-fluidized beds into a request for regular beds with integrated scales. At last measurement, accurate weights were obtained for 94% of all hospitalized patients. This is an example of a problem that was "flying under the radar" for several years that was made visible by the Six Sigma project.

Problems with inconsistency and lack of clarity were addressed. The team agreed on a definition of "6 hours" for the purposes of obtaining the next aPTT (6 hours after the new dose begins at the time the infusion is resumed). The physician who orders the heparin protocol identifies the group that will take responsibility for managing the weight-based protocol. A medication administration record for the weight-based heparin protocol has been developed and has dramatically improved the quality of documentation of heparin administration and monitoring. In addition, infusion pumps with "drug personalities" that restrict the range of infusion rates that can be entered for a given drug infusion will be used for all patients on weight-based heparin. By alerting the nurse to an incorrect rate and requiring manual override, they will reduce the possibility of massive overdose or free-flow infusion errors due to a lapse of attention by the nurse.

Another approach to reducing the complexity and chances for error with the weight-based protocol is to replace it with the use of low-molecular-weight heparin (LMWH), which has been shown to be as safe and effective as unfractionated heparin. It also offers a simpler approach to acute anticoagulation [7], as laboratory monitoring is not required in most cases. At Memorial Hospital, the higher cost of LMWH had been the major barrier to expanding its use. The anticoagulation team estimated the personnel time that would be saved by substituting LMWH and multiplied that by hourly pay rates to calculate an estimated savings with LMWH. Subtracting this amount from the additional cost of therapy resulted in a net savings. Most of the savings will be in nursing time and will not "drop to the bottom line." However, in the face of the current nursing shortage, any simplification of a nurse's job is welcome, and additional available nursing time is highly valued by hospital administration. The reduced complexity of LMWH administration is expected to reduce complexity-related errors. Approximately half of the 1600 patients per year currently receiving weight-based heparin will be eligible for use of LMWH.

Translating opportunities into action steps can be a challenge in the current health care environment. The team conducted a WorkOut, a concentrated problem-solving and implementation technique developed by General Electric, to address mistake-proofing the use of LMWH. Although LMWH will simplify the anticoagulation process, there are still many opportunities for error in its use. The WorkOut

identified a number of mistake-proofing strategies to adopt. One strategy addresses the risk of duplicate administration of LMWH doses. This can occur when a dose is administered but not documented: a second nurse finds a LMWH vial in the patient's medication drawer, administers the dose, and a significant overdose has occurred. The team suggested labeling doses as "AM" and "PM."

The team also conducted WorkOuts aimed at improving adverse drug event reporting and improving communication between laboratory and nursing of critical laboratory values, particularly aPTTs.

The team is designing a plan to support the transition from the weight-based protocol to a LMWH protocol for the treatment of acute coronary syndrome and deep venous thrombosis and pulmonary embolism. The team has addressed policy, safety, educational, and monitoring issues in preparing for this transition. They will also design a system to monitor the extent to which physicians transition from unfractionated heparin to LMWH for these indications and will provide feedback and education to the physicians who do not transition. Unfractionated heparin will remain available for other indications and will continue to be monitored for safety and efficacy using the tools discussed above.

Control Phase

The project will soon be entering the control phase. This is the point at which the important drivers of the process results have been altered, the critical results have improved, and the team prepares for project handoff back to the local process owners. This phase requires the creation of visible metrics ("dashboards") that the process owner will follow to assure that gains are sustained. Examples of such metrics include control charts, run charts, and reports on important process results. A local quality analyst, a member of the quality assurance department who performs chart review and abstraction, will track the performance of acute anticoagulation services on a monthly basis. The charts of patients identified by the automated screening program as not meeting the performance parameters for the 5 Ys (Table 2) will be reviewed in detail and the results reported to the quality director and the pharmacy and therapeutics committee.

Limitations

Six Sigma is a practical, problem-solving methodology. In this approach, statistical tools are used as practical instruments to assist decision making about how to improve processes. This is not a research methodology, and the findings of this project should not be interpreted in the same light as a rigorous clinical research paper. The focus of this paper is to describe an approach for identifying opportunities for improvement and taking action that leads to results that matter to patients in a framework that is achievable in the typical community hospital setting.

Summary

Six Sigma offers a new, structured approach to the improvement of complex processes in health care. Benefits of this approach include comprehensive analysis, objective information for decision making, and a rapid assessment and implementation cycle for improvement. The current project applied an approach to problem solving and patient safety that was different from previous efforts. Improvements to reduce errors have been implemented, and practices have been improved. LMWH, although a more expensive medication, will be substituted where clinically indicated to reduce the complexity of the system. It is expected that reduction of the number of steps in medication administration will improve staff productivity and increase patient safety.

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