Supplement #1

Determining and investigating high priority failure modes

The committee estimated the frequency, severity and ability to escape detection for selected failure modes (Table S1). While failure to access the vein was considered frequent, the severity and ability to escape detection was low. The exception was when the needle missed the vein and entered the adjacent artery. Arterial puncture was considered less frequent but moderate in severity. Although arterial puncture was usually readily detected, it can escape detection in certain situations.

Table S1. Priority Values for Selected Failure Modes

Complication	**Frequency***	**Severity***	**Detection***	**Priority Score****
Retained guidewires	+	++++[1]	++[4]	8
Bloodstream infection	++	++++[2]	++[5]	16
Failure to access vein with needle including arterial puncture	++++	++[3]	+[6]	8

[*] Frequency, severity and ability to escape detection were based on 2006 estimates rather than measured rates. While detailed schemes for calculating priority scores exist, the lack of reliable, objective data on failure mode frequency, severity and detection prompted use of a more subjective scoring scheme in this study.

Frequency: + for 1/month or less, ++ for 1/week, +++ for 1/day, ++++ for >1/day

Severity: + no harm, ++ for minor harm, +++ for harm which required treatment, ++++ for sentinel or “never” event status

Detection: + failure mode is readily and immediately detected, ++ escapes immediate detection, +++ only detected after substantial delay

[**] Priority score determined by multiplying the frequency, severity and detection

[1] Severity increased due to classification as a Joint Commission sentinel event in 2006

[2] Severity increased further in 2008 due to CMS ruling on payment

[3] The high severity score reflects how an unrecognized arterial puncture can lead to arterial catheter placement

[4] By definition, retained guidewires escaped detection during the procedure

[5] Bloodstream infections due to breaks in sterile technique escaped detection during the procedure

[6] Arterial puncture is usually recognized during the procedure but oxygenated blood under high pressure may be absent during certain situations , e.g. cardiopulmonary resuscitation

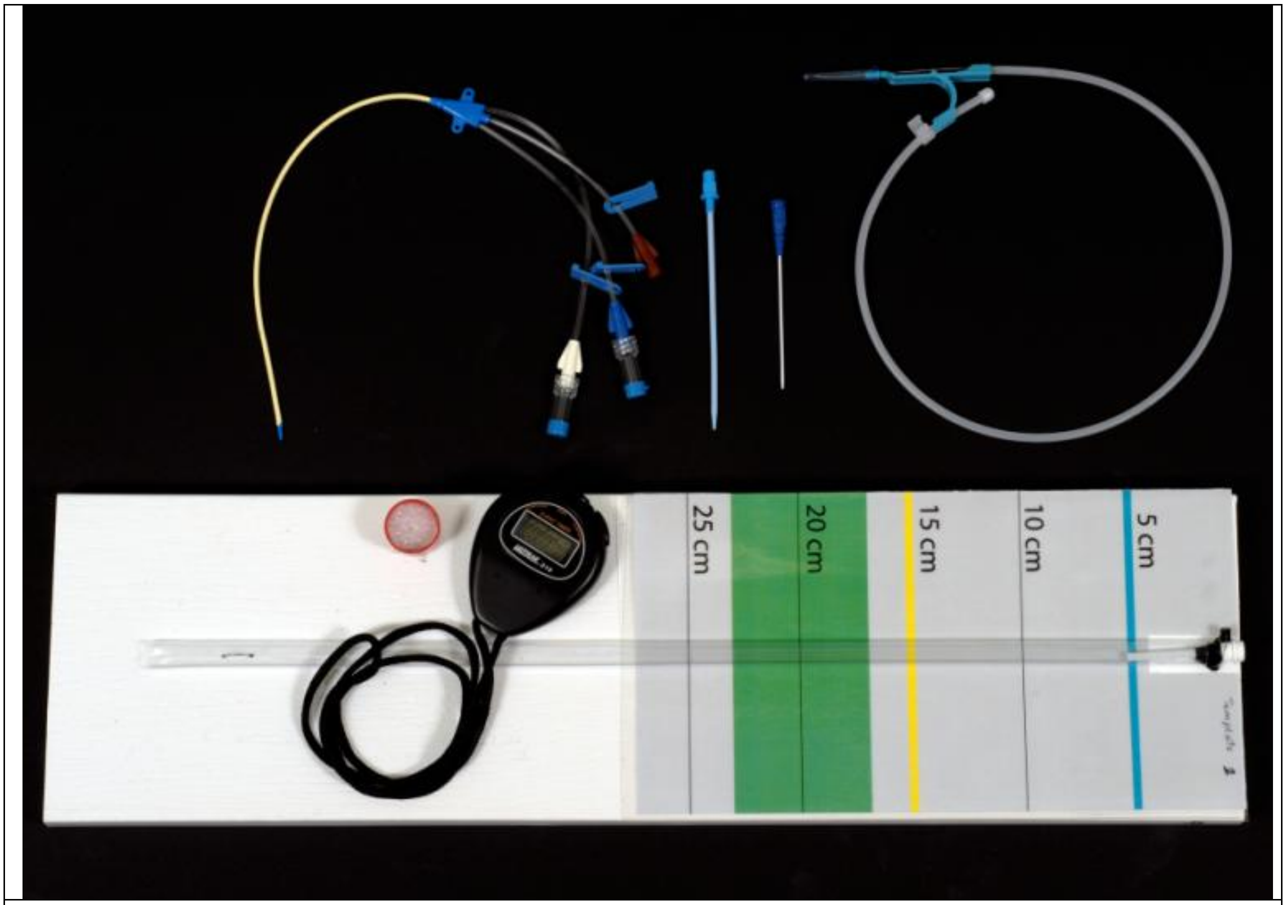

Figure S1. Simulator for catheter and guidewire handling. A clear plastic tube and 9Fr vascular sheath (Cordis Endovascular, Bridgewater, NJ) were attached to a 15 by 55cm plastic board. A template indicating appropriate lengths for inserting the guidewire (green zone), catheter tip (yellow line) and dilator (blue line) from a right internal jugular approach was created, laminated and served as an visual guide. Catheter, guidewire, dilator, introducer and sharps container were purchased as part of a 7Fr triple lumen central venous catheter kit (Teleflex Medical, Reading, PA). This same device was provided to new interns so that they could practice these skills while logged into the online module. Stopwatches were provided to help trainees gauge how their efficiency improved with practice.

The committee used a simple device to simulate errors that might lead to retained guidewires (Figure S1). While some believed that guidewires can be "sucked in" by augmented venous return during deep inspiration, the Interventional Radiologists on the committee reported that they have never seen evidence of guidewires moving in response to blood flow during venous or arterial procedures. Using this simulator, the following sequence was considered the most plausible cause for retained guidewires. First, the operator inserts the guidewire until its tip is well beyond the 20cm mark since that leaves only a short length of guidewire exposed. The short external length of guidewire makes it easier to maintain sterility within a small sterile field. After dilating the tract, the operator threads the catheter onto the guidewire but does not pull back guidewire and grab its free end at the catheter hub before advancing the catheter into position. Finally the catheter is flushed with saline or diluted heparin and the hydrostatic pressure exerted during flushing pushes the guidewire further into the patient. This cluster of failure modes was addressed by teaching new interns to advance the guidewire until its 20cm mark was at the skin surface and keep that mark at the skin surface when dilating the tract or threading the catheter onto the guidewire. Since this meant that a long length of guidewire was left exposed, it was important that a large sterile field was available and this provided an opportunity to emphasize the benefits of maximum sterile barriers.

Supplement #2

Evolution of the Curriculum

The overall curriculum as well as the content of each segment evolved considerably over the last three years. As shown in Figure S2, each change was preceded by content development and testing. When compared to traditional instructor led training, considerably more effort was required to develop, test and revise the online modules. This difference has been observed in other fields and reflects the weaknesses and strengths of online training. Traditional instructor-led courses are a dynamic process where the instructor can monitor trainee behavior and alter content accordingly. While the instructor's ability to diagnose training needs and provide individualized training solutions has clear advantages, it also has two disadvantages. First, each instructor must be able to correctly diagnose which skills are lacking and provide content which addresses those needs. Second, the instructor's time is typically limited and must be coordinated with the trainee's availability. The latter markedly increases the incremental cost of training additional interns and makes it difficult to expand the training program.

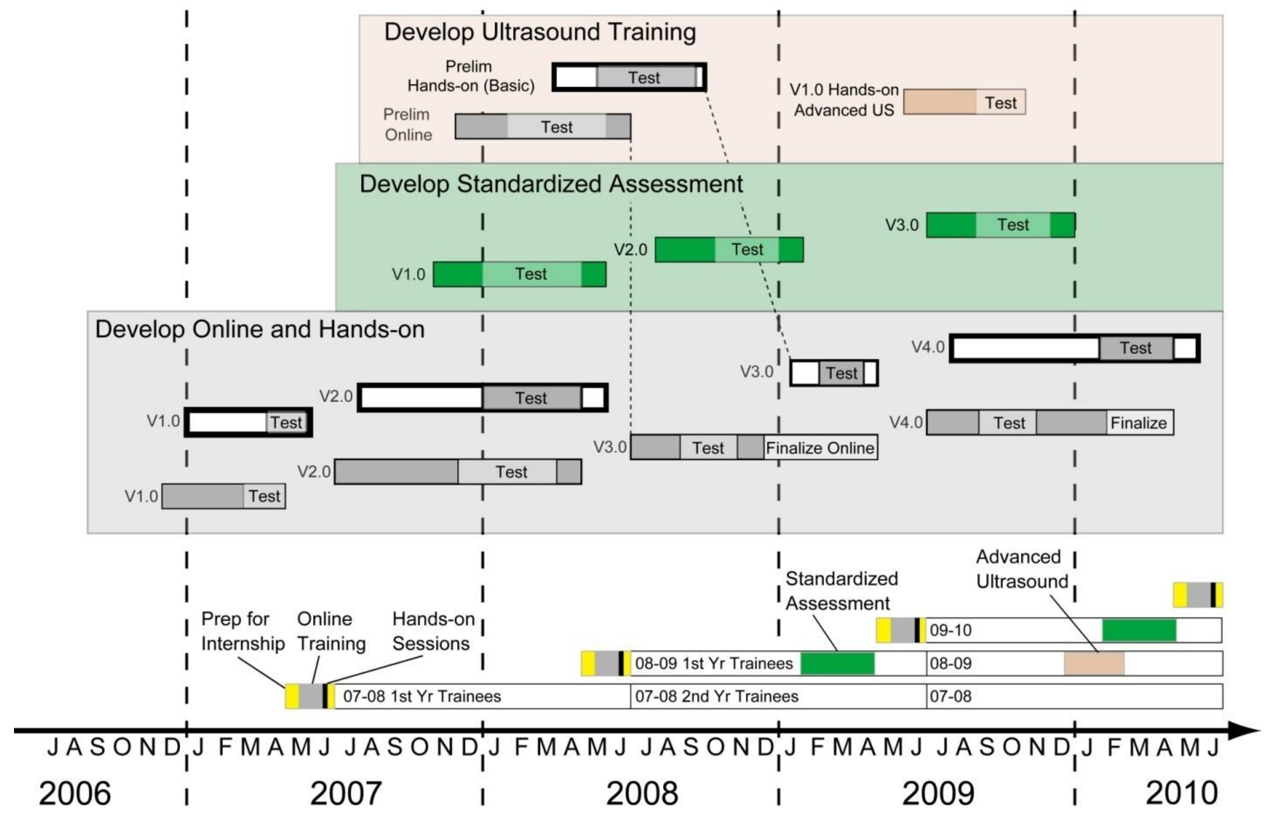

Figure S2. The bottom section illustrates course content for each year's trainees. Online training (gray bar) preceeded hands-on sessions (black bands). The upper sections depict development of the various course segments. The timeline depicts the time required to develop basic skills training (gray box), standardized assessment (green box) and ultrasound training (tan box). Basic skills and ultrasound included both online training (gray bars with thin black outlines) and hands-on segments (white bars with thick black outlines).

In 2008, an online training module on catheter and guidewire skills was added and these skills were reinforced during the hands-on training session. Both the online and hands-on sessions discussed failure modes for catheters and guidewires as well as their implications. Standardized assessment was also introduced to determine if first year trainees possessed the knowledge, skills, and abilities needed to safely perform central venous catheter placement. The most recent course added basic instruction in ultrasound image interpretation. A hands-on session reinforced these concepts by having trainees scan an ultrasound phantom and create images which matched a series of reference images.

Supplement #3

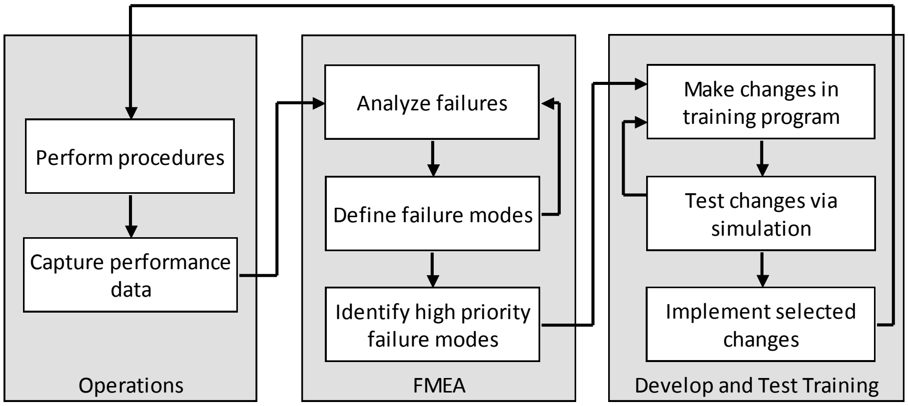

Figure S3. Process map and feedback loops for curriculum development. This flowchart illustrates the central role of Failure Mode and Effects Analysis (FMEA) since it is used to convert performance data into learning objectives. The flowchart also includes a series of feedback loops which promote data-driven continuous process improvement.

Supplement #4

Systematic approach to venous access

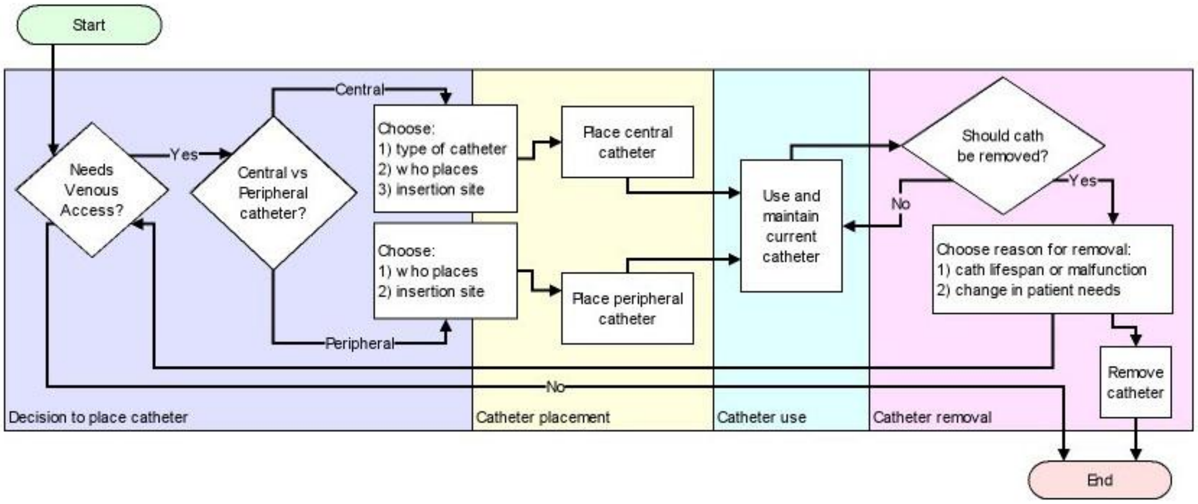

Figure S4. Process map for venous access. The flowchart depicts the various decisions and actions during venous access. It illustrates how central venous catheters and peripheral intravenous lines are part of the solution. In this model, central venous catheters include a wide variety of devices such as peripherally inserted central catheters (PICCs), nontunneled catheters, tunneled catheters, portacaths, dialysis and pheresis catheters.

Duncan JR, Henderson K, Street M, Richmond A, Klingensmith M, Beta E, Vannucci A, Murray D. Creating and Evaluating a Data-Driven Curriculum for Central Venous Catheter Placement. *J Grad Med Educ.* 2010;2(3):389-397.