

Contextual Inquiry of Central Line Placements: Opportunities for Improved Device Design Based on Placement Practices

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Abstract

Background: Central venous catheters (CVC) are indispensable to contemporary critical care, perioperative management, and emergency resuscitation, yet their insertion remains fraught with preventable harm and inefficiency. Large contemporary syntheses estimate that approximately thirty in every thousand patients with a central venous catheter in place for three days will experience at least one serious complication, be it arterial cannulation, pneumothorax, central line-associated bloodstream infection, or deep venous thrombosis, while catheter malfunction alone occurs at roughly six events per thousand catheter-days [1].

Objective: While epidemiologic surveillance and randomized trials may have helped to refine insertion checklists and sterility protocols, far less attention has been paid to the concrete interaction between users, tools, and environments that shapes everyday practice. Human factors frameworks may be an impetus to study actual work as done rather than work as imagined. The US Food and Drug Administration's (FDA) 2016 guidance on applying human factors in medical devices and the Association for the Advancement of Medical Instrumentation (AAMI) TIR51 on contextual inquiry may provide the grounding for early, field-based observation and interview techniques to surface latent use errors, cognitive burdens, and design mismatches before devices reach market or are iterated for safety.

Methods: This qualitative study is a contextual inquiry of CVC placement, which includes observation alongside a brief face-to-face interview with physicians. It is aimed at providing a depth of understanding using evidence to demonstrate causality. A detailed description of the process, tools, and people involved is provided below. The technique, contextual inquiry, is promoted by FDA Human Factors Guidance (2016) to determine user needs at the start of any design process. The data collected in this study includes both observational and interview data with three main areas of focus: the user, environment, and tasks as part of the steps and workflow.

This study was conducted at three different hospitals, within the Emergency Department (ED), the Intensive Care Unit (ICU), and operative rooms (OR). Where possible and with additional consent, sessions were recorded in video or still photography, or at times both. The study included a total of 19 observations and 24 interviews.

Results: Viewed through the intersecting lenses of safety, efficacy, and usability for patients, providers, and products, our findings provide the basis for an argument that a device ecosystem should simultaneously consider the following precepts: (1) shields patients from infection, vessel injury, and the cascade of "extra" procedures (intubation, deep sedation) by shortening setup and puncture time and by making correct J?wire orientation and tip control essentially foolproof; protects clinicians from sharps and blood under tension, awkward postures, and protocol drift by embedding ergonomic grips, one-handed aspiration

aids, and closed, labeled receptacles that keep contaminated instruments off ad hoc trays; and (3) streamlines the product itself with sequential, memory-light assembly, color/texture coding, and built-in safeguards (e.g., wire funnels, depth markings visible through bloodied gloves, lockable sharps wells) that are robust and attuned for real-world conditions like low light, urgent timelines, moving patients, and gloved, fatigued hands. In effect, an intuitive kit that aligns with predictable human behavior and eliminates unnecessary multistep detours can reduce novice failure rates, cognitive load, and practice inconsistency just as it could serve to curb non-recyclable waste from “backup” kits opened for a single missing item. By reframing CVC systems as socio-technical solutions rather than static assortments of parts, the same design moves that minimize improvisation and coordination errors for providers also compress dwell time and manipulation events for patients, thereby advancing the core triad of safety, procedural efficacy, and everyday usability

Conclusions: By looking closely at how clinicians actually place central lines, this study exposes modifiable design faults that perpetuate risk despite decades of procedural standardization. Contextual inquiry provides the evidentiary bridge between clinical imperatives to reduce complications and the practical realities of device use.

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Original Manuscript

Contextual Inquiry of Central Line Placements: Opportunities for Improved Device Design Based on Placement Practices

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Introduction

Central venous catheters (CVC) are indispensable to contemporary critical care, perioperative management, and emergency resuscitation, yet their insertion remains fraught with preventable harm and inefficiency. Large contemporary syntheses estimate that approximately thirty in every thousand

patients with a central venous catheter in place for three days will experience at least one serious complication, be it arterial cannulation, pneumothorax, central line-associated bloodstream infection, or deep venous thrombosis, while catheter malfunction alone occurs at roughly six events per thousand catheter-days [1]. Central line-associated bloodstream infections still claim thousands of lives each year in the United States and add billions of dollars to health care costs, despite decades of prevention bundles and increasingly routine ultrasound guidance intended to curb mechanical mishaps and accelerate successful cannulation [2].

While epidemiologic surveillance and randomized trials may have helped to refine insertion checklists and sterility protocols, far less attention has been paid to the concrete interaction between users, tools, and environments that shapes everyday practice. Human factors frameworks may be an impetus to study actual work as done rather than work as imagined. The US Food and Drug Administration's (FDA) 2016 guidance on applying human factors in medical devices and the Association for the Advancement of Medical Instrumentation (AAMI) TIR51 on contextual inquiry may provide the grounding for early, field-based observation and interview techniques to surface latent use errors, cognitive burdens, and design mismatches before devices reach market or are iterated for safety [3,4].

The present study applies a structured contextual inquiry across three hospitals and multiple care settings to showcase how central line placement actually unfolds, minute by minute, from pre-sterile preparation through dressing application. By triangulating in situ observation with brief clinician interviews, we catalogued 34 discrete steps, mapped procedure time distributions, and documented recurrent friction points that compromise sterility, ergonomics, and situational awareness. Drapes that obscure a conscious patient's face, guidewires that kink or become blood-slick, ultrasound monitors positioned outside the operator's line of sight, and kits that omit essential or preferred components collectively can provide a basis for clinicians to improvise, potentially increasing cognitive load and exposure to sharps and biohazards. These granular insights are intended not merely to critique current practice, but to specify actionable requirements for next-generation kit architecture, accessory design, and room layout that align with real user needs in chaotic and controlled environments alike.

Materials and Methods

This qualitative study is a contextual inquiry of CVC placement, which includes observation alongside a brief face-to-face interview with physicians. It is aimed at providing a depth of understanding using evidence to demonstrate causality. A detailed description of the process, tools, and people involved is provided below. The technique, contextual inquiry, is promoted by FDA Human Factors Guidance (2016) to determine user needs at the start of any design process. The data collected in this study includes both observational and interview data with three main areas of focus: the user, environment, and tasks as part of the steps and workflow.

This study was conducted at three different hospitals, within the Emergency Department (ED), the Intensive Care Unit (ICU), and operative rooms (OR). Where possible and with additional consent, sessions were recorded in video or still photography, or at times both. The study included a total of 19 observations and 24 interviews (Table 1). The total number of observations and interviews conducted at each site was determined by the clinical need and patient-clinician consent at the time of the study. In the instances that patient consent was not provided yet physicians wanted to participate, the physicians could opt to demonstrate their placement technique using a simulated patient within the care environment.

Table 1. Breakdown of observations and interviews by location

	Cincinnati, OH	Wake Forest, NC	Sacramento, CA	Total
Observations	9	7	3	19

Interviews	8	8	8	24
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A total of 24 physicians were involved in this study and included emergency medicine, critical care, and anesthesiology specialists. Observations and interviews were conducted in perioperative rooms, operating rooms, emergency departments, as well as intensive care units. Within each hospital, the same brand of kit was used; however, in one instance at Wake Forest there was a different type of kit used between the OR and that of the ICU and ED. The kits consisted of different brands and product identification numbers (Table 2).

Table 2. Brand of kits used by location and environment of care

	Cincinnati	Wake forest	Sacramento
OR	Edwards MULTI-MED Central Venous Catheter <i>3K20N18141NL</i>	Arrow Central Venous Access Kit <i>ASK-21242-PCMH1</i>	Arrow Blue Plus Pressure Injectable Multi-Lumen CVC Kit <i>ASK-45703-PIO</i>
ICU	Edwards MULTI-MED Central Venous Catheter <i>3K20N18141NL</i>	Arrow Pressure Injectable Multi-Lumen CVC Kit <i>CDC-45703-XP1A</i>	Arrow Blue Plus Pressure Injectable Multi-Lumen CVC Kit <i>ASK-45703-PIO</i>
ED	Edwards MULTI-MED Central Venous Catheter <i>3K20N18141NL</i>	Arrow Pressure Injectable Multi-Lumen CVC Kit <i>CDC-45703-XP1A</i>	Arrow Blue Plus Pressure Injectable Multi-Lumen CVC Kit <i>ASK-45703-PIO</i>

Results

In this study, the average overall time for a CVC to be placed varied across the care environments (Table 3). In discussion with clinicians, some of them postulated that procedure times vary proportional to the amount of control the provider perceived to have over the patient and environment (i.e. postulating that the more chaotic the environment, the longer the procedure).

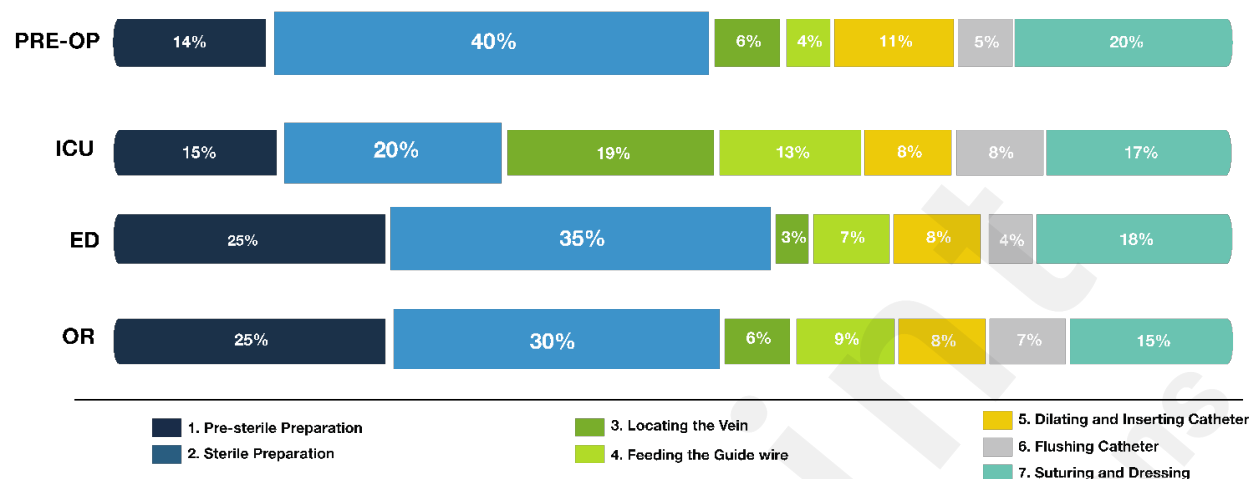
Table 3. Average central venous catheter placement timing in different environments of care

Environment	Average Time (hr:min:sec)
Operating Room	0:16:48
Pre-Operative Care	0:20:15
ICU	0:27:53
Emergency Dept	0:35:28

Procedural timing was also broken down into seven distinct sections within the overall procedure (Figure 1). These include the following: pre-sterile preparation, sterile preparation, locating the vein, feeding the guidewire, dilating and inserting the catheter, flushing the catheter, and suturing and dressing. Of note, procedure preparations from pre-sterile to sterile preparations accounted for more than half the overall procedure time in all locations aside from the ICU environment. It was noted by the research team that the number of staff participating in setting up for

the procedure varied across sites as well as environments of care.

Figure 1. Percentage of time per section of the central venous catheter placement procedure based on environment



The patient experience during CVC placement highlights conditions that impact overall safety, efficacy, and usability. Draping a conscious patient can be problematic. During procedure preparation, the provider unpacks sterile drapes from a kit and prepares a sterile field directly over the patient (Figure 2). This extends the working sterile field, albeit an unstable one, directly on top of the patient. As a result of patient movement, required equipment for the procedure can fall out of the sterile field or become lost. Uncooperative patients require additional procedures, such as intubation, muscle relaxation and sedation, prior to CVC placement.

Figure 2. Patient acting as an extended sterile work surface



In the OR, the patient is intubated and unconscious. However, in the ED and ICU environments, the patient was often conscious and mobile. Draping in all cases covered the patients face throughout the procedure, yet risked having a claustrophobic and difficult environment (Figure 3). In clinical practice, there is a high degree of variability in body habitus across the patient population. As a result, drapes provided in the kits may not fit patients classified as obese. In some

cases, the aperture provided by the drape is not large enough to accommodate the insertion location and thus can result in the provider improvising by creatively engineering a larger opening.

Figure 3. Patient drape placed over patient face in the intensive care unit



Patient airways require management throughout the procedure. In this study, patients in the ICU were fitted with an oxygen mask. A mask is often placed in case of a future need to avoid disturbance of the sterile field.

Gaining access and positioning can often lead to patient discomfort. Patients are required to hold awkward trendelenburg positions with their head turned and extended to optimize their anatomy for successful CVC placement (Figure 4). Patients were instructed to maintain position throughout the procedure, though it can be uncomfortable as the plastic portion of the drape can be just upon a patient's skin. For a conscious patient, this did at times result in the need for further anesthetic as well as some challenges for the providers in that, as access is gained, patients would move. This position proves challenging for patients who are obese who may also require additional supplies and longer periods of time to complete procedure preparation.

Figure 4. Aperture opening of the drape adhered directly to a patient's face



The provider experience during CVC placement also underlines conditions which could impact overall safety, efficacy, and usability. Providers are required to don personal protective equipment (PPE) in tight spaces without compromising sterility (Figure 5). In this study, the order of preparation varied across locations of care. For example, ED providers at times elected to pre-clean the patient prior to gowning which allowed time for the chloraprep to dry, whereas in the OR some of the providers prepared PPE in advance.

Figure 5: Donning of personal protective equipment in a tight space



The overall procedure is a quite complex with multiple steps within each phase. As observed, there were six steps to pre-sterile preparation, eight steps to sterile preparation, four steps in locating the vein, three steps in feeding the guidewire, four steps to dilate and insert the guidewire, three to flush the guidewire, two to suture, and four to place the dressing. This equates to 34 steps which require the provider to locate key pieces of equipment, locate where and how to use it, all while either developing or maintaining a sterile workspace. During this multi-step process providers often improvise, which may tax a heavy cognitive burden and require coordination.

Across all sites and use environments, a minimum of two providers were present. This enabled one sterile operator and one support person who enabled adjustments of patient drapes, including the use of an OR towel to protect the patients' face, as well as the retrieval of items that were required but not readily found in the kit or simply forgotten, or sterile preparation of the ultrasound probe.

Providers are often in awkward positions with non-optimized biomechanics because of product design or the room layout, or both. For example, flushing with a standard syringe requires an uncomfortable and awkward hand movement required to achieve aspiration as the device is designed to deliver a solution. When ultrasound is used for safe access, both hands are required to hold equipment and can thus make aspiration a one-handed motion (Figure 6).

Figure 6. One-handed aspiration while holding ultrasound probe



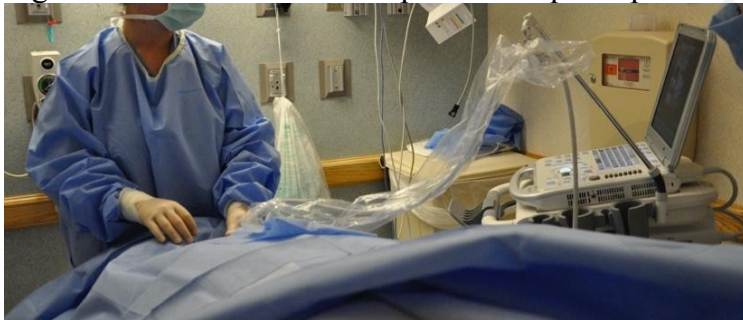
Providers held the syringe and introducer needle at a 45-30-degree angle and subsequently lowered the angle while advancing the needle (Figure 7). To verify position, providers would draw more blood and assess color as well as pressure gradient. This step was commented by some to be the highest 'stress' point in the procedure. One intensivist even remarked that finding the vein was the most stressful part, and that once the wire is in and the needle is out their stress subsides. It is at this point that there is risk of pneumothorax or perforation of the carotid artery. It was observed that it is ergonomically difficult for providers to maintain stability and aspirate to visualize venous blood return. This is further complicated by the ultrasound monitor placed outside the providers point of view (Figure 8). Additionally, the pressure the user places on the vein with the ultrasound probe can

cause the central venous anatomy to change when the device is pulled away from the skin surface. Providers are compelled at times to make slow, careful movements, with the risk controlled by the user's experience. Rather than an intuitive device design, advanced troubleshooting or error prevention throughout the procedure can be dependent on provider experience and dexterity.

Figure 7. Access needle angle relative to the ultrasound probe



Figure 8. Ultrasound monitor position requires providers to look away from the access site



While simultaneously troubleshooting and preventing errors, providers are exposed under some tension to sharps and biohazards. Once access to the vein is achieved, users are exposed to the access needle where skin incision scalpel is typically contaminated with the patient's blood within the working area (Figure 9). While efforts were made to control and maintain safety of sharps, the CVC kit design places the cognitive burden, safety, and responsibility upon the provider. As vein dilation occurs, the access site often becomes very disordered and presents a biohazard to the providers (Figure 10). Once the vein was dilated, increased blood flow increased the stress and inconvenience of the procedure, in that, the guidewire itself became a slippery surface and could have become misplaced in the patient requiring additional intervention. This hazardous situation also extends to catheter insertion (Figure 11). Providers are required to thread the catheter over the guidewire and had adopted a coiling behavior to maintain control and reduce proximal tip movement, which can complicate device alignment (Figure 12). These situations are particularly challenging for novice providers as they grapple with each step of the procedure (Figure 13). Consequently, inexperienced providers often have unsuccessful attempts at placement of CVCs.

Figure 9. Open kit mid-procedure with sharps anchored in the kit



Figure 10. Advancement of the dilator over the wire in slippery conditions due to venous return



Figure 11. Catheter insertion with exposure to biohazard

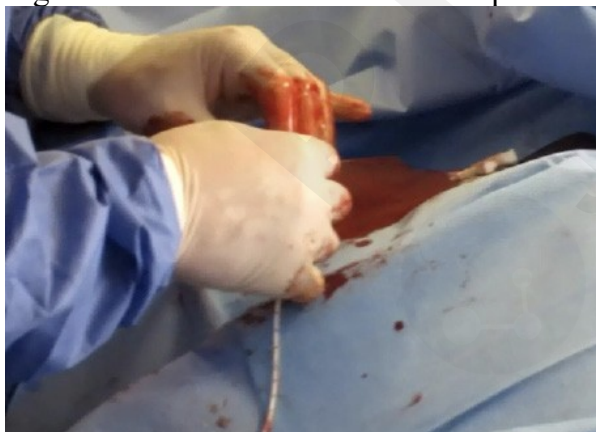


Figure 12. Coiled guidewire enabling control during catheter insertion



Figure 13. Novice users have increased exposure to biohazards



The product design of traditional CVC kits is not entirely always optimized for streamlined assembly. Many kits for example did not have all the supplies or the preferred supplies for CVC placement. Some providers in the study noted that they'd have wishes for saline or appropriate valves or noted that they felt the kits had not changed much over the years. As a result, clinicians often spend additional time gathering the necessary materials (e.g., skin prep, gauze, saline, and lidocaine) as well as preferred materials because the valves provided in the kits are at times not compatible with other hospital equipment. Some users preferred vertical valves such as clave connectors (Figure 14). Providers who prefer to use non-standard or additional supplies may often open a secondary kit that is sourced from separate locations within the hospital. Items collected may include additional drapes, mayo stand, lidocaine, sterile flush syringes, chloraprep, and ultrasound devices/supplies.

There were no safeguards for disposal of all sharps. When providers remove the guidewire there is no proper receptacle to place it in, therefore it was thrown away with non-sharp materials. It is often the case that providers do not use sharps holders during the procedure, rather preferring to leave sharps on the tray (Figure 15). There is a considerable amount of non-recyclable waste and challenges because of kit design (Figure 16). In this study, the kits at times lacked a clear delineation between the kit layers that designate items regarding what they were and when they should be used. There were excess materials that were not used in the procedure which contributed to the overall waste produced. Providers often drape the sterile area and manipulate the drape around the patient's face and head region, such that the patient has an easier time breathing and to eliminate claustrophobia.

Quality and design of the CVC products individual elements poses usability challenges, including malalignment with predictable human behavior, a heavy reliance on memory, and a lack of visual or tactile references. One challenge in this study was that the guidewire kinks frequently. When this happens, providers would often try to remove the kink or use the wire regardless. If this guidewire is rendered unusable, the provider may open a new kit to replace the failed one or in some instances a missing part (Figure 17). What's more is that the dilator is the same color as the draping and can get camouflaged and lost in it. Additionally, due to the complex set-up, components sometimes fell outside of the sterile field. Another detail that has caused some difficulty on the guidewire design includes the "J" curve. While it can provide safe intravascular advancement, this curve on the wire can also make the guidewire more difficult to thread into the catheter. Some providers were observed making what some may describe as counterintuitive work arounds, and flipped to the straight end of the guidewire to easily advance it through the catheter. Though well intended, this variation in CVC placement may increase the risk of complications. Furthermore, there was little to no tactile feedback on the guidewire feeder, which makes it difficult for the user to know if the wire is advancing. This is further complicated by gloves stained with blood, which make the markings of the guidewire difficult to see and grasp. The results of these outdated design decisions can create an unnecessary burden on providers to judge catheter alignment on the guidewire and insertion depth.

Figure 14. Different forms of valve connectors



Figure 15. Sharps placed on top of kit during the procedure



Figure 16. Waste accumulation because of kit design



Figure 17. Three kits opened for the guidewire and dilator due to kinking



In this study, the CVC placement procedure was consistent across hospitals and care environments with limited exceptions spanning a few sections such as suture and the use, or lack thereof, of dressing in specific care environments, (e.g., suture and dressing use/lack of use in specific care environments). The described and observed difficulties leave room for improvement in device design (Table 4).

Table 4. Summary of use related issues throughout the procedure

Procedure Section	Device(s) used	Problem Area (s)
Pre-Sterile	CVC Kit	Does not include all essential materials needed for central line placement resulting in unnecessary delays. Ability to distinguish non-sterile and sterile items during non-sterile preparation.
	Non-sterile syringe	Providers typically empty 3-5 syringes (30-50mL) of saline solution into the kit basin from non-sterile saline syringes. These are not included in the kit.
	Lidocaine	Because the lidocaine is not sterile, providers will either have someone hold it for them, tape it to a Mayo cart, or chase down the ampule while loading the syringe.
Sterile	Patient Drape	Due to the discomfort caused by the full body drape it makes it more difficult for the provider to maintain sterility and manage the patient during the procedure.
Locating Vein	Introducer Needle	Providers expressed preference toward the 18G introducer needle without a catheter over the 20G needle with 18G catheter assembly. For obese patients, providers noted that the length (2 ½") of the needle was not long enough. The introducer needles were not echogenic, thus they are difficult to view in the ultrasound monitor.
	Ultrasound	The ultrasound monitor was not placed within the line of sight of the provider making it difficult for the provider to effectively use the tool. Providers don't generally document ultrasound use by capturing an image of the procedure as required by major insurers for reimbursement.
Feeding the Guidewire	Guidewire	Wire kinking while executing the procedure was problematic and once deemed unusable, the provider would open another kit only to access an additional wire.
		The "J" tip of the wire was difficult to thread and feed.
		Providers had difficulty estimating how much of the wire is inserted. If they are unsure, they will take the wire out of the delivery system. Once the wire is removed from the delivery system it is difficult to reload, thus once it is out, it typically stays out. Markings on the wire are also not clear for the provider.
		Due to the inherent messiness of the procedure, blood is often on the provider's hands making it difficult to handle the guide wire delivery system.
Dilating and Inserting Catheter	Dilator	The dilator will often kink if the provider is aggressively pushing. If the dilator is no longer usable another kit will be opened only to access another dilator. The dilator length (4") is not long enough for obese patients.
	Catheter	Threading the catheter over the wire is a difficult task. Providers will have a hand tremor when performing this task.
		It is difficult for the provider to determine if the tip of the catheter has reached the superior vena cava. Providers will estimate placement and follow-up X-raying the patient to confirm proper placement.
Flushing Catheter	Syringe	Observed challenge in the syringe grip during aspiration and flushing. Providers will struggle with the current syringe design to alternate between two grips.
		The T-shaped valves provided in the kit also present challenges

Discussion

This contextual inquiry reveals that central venous catheterization is not merely a sequence of technically codified steps but an intricate socio-technical performance in which device design, environmental constraints, and clinician improvisation intersect to shape risk. Our mapping of 34 discrete actions, the dominance of preparation time in most settings, and the recurrent need to compensate for missing or poorly engineered components align with contemporary estimates that roughly 3% of patients exposed to a catheter for three days sustain a major complication [1]. It is evident that even small frictions at the bedside matter: each added reach across a compromised sterile field or each visually obscured monitor may incrementally elevate the probability of infection, misplacement, or operator injury. Large contemporary reviews showcase that CVC is now routine, roughly 8% of hospitalized patients need a CVC and more than five million are placed annually in the United States, and that ultrasound-guided puncture should be the default, yet our observations of obscured monitors, awkward one-handed aspiration, and improvised wire handling show how the safest technique on paper can still be undermined by poor ergonomics and kit design [5].

Our findings build off imperatives for field-based inquiry into real work conditions to surface latent design hazards. We observed exactly the kinds of use errors that are of concern: kinking guidewires without tactile feedback, dilators camouflaged against drapes, valves incompatible with existing hospital hardware, and ultrasound displays positioned outside the operator's natural sightline. Such mismatches between device affordances and predictable human behavior may shift cognitive burden to clinicians, who must remember workarounds and coordinate ad hoc assistance while maintaining sterility. A contextual inquiry approach is designed to elicit these mismatches; our study demonstrates its value in an acute, invasive procedure where seconds and millimeters carry consequence. The imperative to integrate these insights into formal design controls is clear.

Several concrete implications for device and kit redesign emerge from our contextual findings and accord with human-factors guidance that interventions must fit users' capabilities, workflows, and environments to sustain adoption and fidelity [6–9]. Rather than perpetuating one-size-fits-all assortments, kits could be organized and sufficiently complete for the intended procedure and patient mix, thus minimizing secondary searches and redundant openings, so that routinely needed sterile flushing media, local anesthetic, echogenic introducer needles of adequate length for patients classified as obese, and valve connectors compatible with local infusion hardware are immediately available; these specific component choices derive from our observations, while the general mandate to reduce cognitive and physical load is articulated in human-centered design literature [6,9]. High-risk elements could incorporate salient visual and tactile affordances, such as example, blood-tolerant depth markings on guidewires, textured feeders that signal advancement, and color-contrasted dilators that cannot visually disappear against drapes, an approach consistent with human-factors recommendations to engineer cues that support rapid, accurate action under stress [9]. Ultrasound ergonomics require particular attention: practice reviews emphasize that the operator should keep the puncture site, needle, and image within a single line of sight, yet we repeatedly observed monitors positioned laterally or behind the user, encouraging awkward posture and one-handed aspiration [6–8]. Converging evidence from simulation and ergonomic assessments shows that suboptimal screen and table positioning increases musculoskeletal strain and facilitates needle-advancement errors, especially among novices, supporting the design of articulating mounts, probe-holding accessories, and workstation layouts that free the dominant hand and keep the image within the operative field [7–9].

Patient experience is also somewhat inseparable from considerations of safety. Drapes that blanket a conscious patient's face created anxiety and impeded airway access, while Trendelenburg positioning with head rotation was difficult to sustain, particularly for individuals classified as obese who then required additional supplies and time. Our observations suggest that rethinking drape architecture to permit facial exposure without compromising sterility, and integrating oxygen

delivery ports or transparent windows, could mitigate claustrophobia and facilitate airway monitoring. Because central line-associated bloodstream infection (CLABSI) remains among the costliest hospital-acquired infections on a per-case basis, the marginal gains from such design tweaks may translate into substantial economic and human benefit when scaled across millions of annual insertions [10]. Even in the era of prevention bundles, catheter dwell time remains a potent infection driver; CLABSI rates in one two-year adult cohort climbed from 4.80 to 8.64 per 1,000 catheter-days as dwell exceeded 20 days, with multidrug-resistant *Acinetobacter baumannii* predominating, mirroring some of our concerns that missing components, repeated kit openings, and ad hoc maintenance steps prolong set-up and line life, thereby compounding exposure to contamination [11]. It has been previously emphasized that complication profiles can hinge on site choice, catheter caliber, and positioning - adult data (e.g., 3SITES) link subclavian access to fewer infections but more pneumothoraces, whereas pediatric series show different risk patterns - and it has been reiterated that neutral rather than exaggerated positioning and meticulous ultrasound use can reduce failed passes and arterial hits, resonating with our field notes on stressful needle advancement angles, off-axis screens, and repeated punctures at the point deemed to be of the highest stress [12]. Other recommendations also somewhat align with our design proposals: select the smallest necessary lumen count, favor non-tunneled catheters for <3-4 weeks and peripherally inserted central catheters (PICC) when therapy exceeds six days, cap prolonged catheterization (approximately 14 days) to curb bacteremia, mandate real-time ultrasound, chlorhexidine-alcohol prep, and daily site surveillance [13]. These are practices that our contextual inquiry somewhat related to and found were variably executed or actively hindered by kit incompleteness, unclear layer sequencing, and drapes that compromise both sterility and patient comfort. In a simulation of 40 anesthesia providers, patient safety (mean importance score 83.9/100), ease-of-use (64.6/100), and reduced clinician error (61.1/100) topped the selection criteria, and a novel CVC system with a sequentially organized tray, enhanced labeling, and a guidewire funnel earned significantly higher satisfaction overall, for ease-of-use, layout, safety (all $p \leq 0.012$), and for reducing five of seven common risks (including clinician error and contamination/infection), aligning with the usability deficits (wire kinking, component hunting, ambiguous tray hierarchy) our study cataloged [14].

The study also highlights how waste and sharps handling are downstream consequences of kit design. Absence of designated receptacles for used guidewires and scalpels, lack of sharps holders integrated into trays, and the routine opening of multiple kits for single missing parts create biohazard exposure and substantial nonrecyclable waste. While our qualitative approach did not quantify environmental impact, other health systems work has emphasized the financial and ethical importance of reducing unnecessary disposables; future prototypes should therefore embed closed-loop sharps capture and minimize redundant components to support infection prevention and sustainability goals simultaneously. This is an inference from our data that warrants targeted life-cycle and cost analyses in subsequent studies.

Viewed through the intersecting lenses of safety, efficacy, and usability for patients, providers, and products, our findings provide the basis for an argument that a device ecosystem should simultaneously consider the following precepts: (1) shields patients from infection, vessel injury, and the cascade of “extra” procedures (intubation, deep sedation) by shortening setup and puncture time and by making correct J-wire orientation and tip control essentially foolproof; protects clinicians from sharps and blood under tension, awkward postures, and protocol drift by embedding ergonomic grips, one-handed aspiration aids, and closed, labeled receptacles that keep contaminated instruments off ad hoc trays; and (3) streamlines the product itself with sequential, memory-light assembly, color/texture coding, and built-in safeguards (e.g., wire funnels, depth markings visible through bloodied gloves, lockable sharps wells) that are robust and attuned for real-world conditions like low light, urgent timelines, moving patients, and gloved, fatigued hands. In effect, an intuitive kit that aligns with predictable human behavior and eliminates unnecessary multistep detours can reduce novice failure rates, cognitive load, and practice inconsistency just as it could serve to curb non-recyclable waste from “backup” kits opened for a single missing item. By reframing CVC systems as socio-technical solutions rather than static assortments of parts, the same design moves

that minimize improvisation and coordination errors for providers also compress dwell time and manipulation events for patients, thereby advancing the core triad of safety, procedural efficacy, and everyday usability.

Limitations

Our findings should be interpreted in light of several limitations. The study was conducted in three US hospitals and included 19 observations and 24 interviews, which constrains generalizability, particularly to resource-limited settings or institutions that use different kit vendors. Although we captured real procedures, observer presence and video recording may have altered behavior, and some demonstrations on simulated patients cannot fully reproduce the stressors of an emergent cannulation. We did not measure clinical outcomes linked to the specific use problems we identified, nor did we quantify cognitive load or musculoskeletal strain through quantitative measures. Furthermore, our sample focused on physicians; nurses, technicians, and infection preventionists often influence setup, maintenance, and post-placement care, and their perspectives warrant inclusion in a fuller systems analysis.

Conclusion

Future work should transition from description to intervention. Rapid-cycle prototyping informed by these contextual insights, followed by high-fidelity simulation and usability testing per relevant guidelines could generate validated design changes. Eye-tracking, motion capture, and workload assessment tools may quantify how redesigned components alter gaze patterns, posture, and error rates. Multicenter trials comparing integrated, human-centered kits with current products could measure effects on insertion time, complication rates, waste generation, and cost. Furthermore, translating these methods to maintenance phases, including line access and dressing changes, could extend human factors benefits beyond placement to the full catheter life cycle.

By looking closely at how clinicians actually place central lines, this study exposes modifiable design faults that perpetuate risk despite decades of procedural standardization. Contextual inquiry provides the evidentiary bridge between clinical imperatives to reduce complications and the practical realities of device use. Embedding such inquiry at the outset of design and iteratively throughout product life cycles offers a path toward safer, more efficient, and more humane central venous access.

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