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Prevention of CAUTIs, CLABSIs, and VAPs in Children

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Opinion statement

Given the lack of randomized controlled trials or robust literature in children, we are left with recommended bundles, adult-based literature, and common sense. The quality improvement approach to studying prevention of hospital-acquired infections through the use of bundles has generally been studied *en masse*, rather than by individual bundle elements. Due to the mortality risk, indirect and direct attributable costs, and the inevitable penalties associated with these largely preventable harms, we must reliably implement bundles to avoid these hospital-acquired infections. "Implementation is the most difficult but most essential aspect of harm prevention". The journey to zero harm, whether infectious or not, will ultimately require a robust safety culture, incorporation of high reliability principles, and patient and family engagement.

Introduction

Healthcare-associated infections (HAIs) are a significant threat to patient safety and a large source of cost, morbidity, and mortality within our healthcare system. In the US, the estimated yearly incidence of HAIs in adult and pediatric patients is between 722,000 and 1.5 million events resulting in approximately 75,000 to 100,000 patient deaths; one quarter of HAIs occur in patients in ICUs or high risk nurseries [1, 2]. In pediatric intensive care unit (PICU) patients, the most frequent HAIs are bloodstream infections (~28%), pneumonia (~21%), and urinary tract infections (~15%) [3]. In a recent European study, the prevalence of HAIs was 15.5% in PICUs and 10.7% in NICUs, though pediatric oncology units were not listed as a distinct location from the wards [4]. Thus, our review will focus on the most common HAIs in children: central line-associated bloodstream infections (CLABSI), ventilator-associated pneumonia (VAP), and catheter-associated urinary tract infection (CAUTI).

Solutions for Patient Safety (SPS), an organization which evolved into a national quality and safety network in 2012, has published multiple pediatric prevention bundles for various hospital-acquired conditions [5]. Operational definitions of harm and evidence-based bundles designed to prevent harm have undergone multiple revisions and now exist to aid pediatric hospitals in the prevention of CLABSI, CAUTI, ventilator-associated events (VAEs), and surgical site infections [6••, 7]. This collaborative, partially funded by Centers for Medicare & Medicaid Services, has become a leading player in the prevention of hospital-acquired harm in children.

Definitions

In order to reduce HAIs, it is worthwhile to understand the definitions applied to these infections, though they are most often used when attempting to determine whether an infection meets the criteria for the operational definition. However, clinical infections do not necessarily correlate with regulatory definitions, and a patient who clinically appears infected must be treated as such. The CDC defines laboratory-confirmed bloodstream infections as one of the three types, and the first two types apply to any age patient whereas the third type involves criteria that apply only to children <1 year old [8]. Additionally, mucosal barrier injury laboratory-confirmed bloodstream infections apply to a subset of oncology patients who have bloodstream infections caused by a specified list of enteric organisms [8]. The CDC also defines symptomatic urinary tract infections, asymptomatic bacteremic urinary tract infections, and urinary system infections, which have specific criteria as well [9].

In January 2017, the CDC defined VAE and began requesting data based on this new definition, which specifically excluded children [10]. VAE refers to a family of events that includes infectious ventilator-associated condition (iVAC), and non-infectious VAEs. Instead, the CDC requests hospitals to continue submit pediatric and neonatal data based on the ventilator-associated pneumonia definition, which is based on radiologic and clinical criteria. SPS has transitioned to collecting pediatric VAE data starting January 2017 [7]. The current SPS definition of pediatric VAE utilizes mean airway pressure (MAP) and fraction of inspired oxygen (FiO2) in a patient who has had at least 2 days of stability or improvement followed by a minimum FiO2 increase of >25% and daily MAP increase of >4 over ≥2 days [7]. The daily minimum values must be maintained for at least 1 h. The definition is developed based on a study of ~9000 children in neonatal, pediatric, and pediatric cardiac intensive care units (ICUs) [11]. Patients excluded from the definition are those with artificial lungs, on extracorporeal membrane oxygenation, using airway pressure release ventilation, or using volumetric diffuse respirators. This definition does include neonates, patients with a tracheostomy, patients on high frequency oscillatory ventilation, and patients on high frequency jet ventilation. According to the definition, patients can have a VAE no more than every 14 days. The definition is transitioning, as conditions other than pneumonia may harm patients on a ventilator. Non-infectious VAEs include conditions such as fluid overload, aspiration, and mechanical issues. For now, hospitals continue to report pediatric VAPs to the National Healthcare Safety Network, and pediatric VAEs to SPS. Most bundles target prevention of VAP, as the VAE definition is relatively new.

The CDC provides useful flowcharts for diagnosis of primary and secondary HAIs. The definitions are complex and change frequently so the CDC site should be referenced for the most up-to-date definition [8–10, 12].

HAI preventability and cost

The majority of HAIs are considered to be preventable. Multicenter collaboratives believe that by using current HAI risk reduction strategies, more than 70% of CLABSIs and CAUTIs and up to 55% of VAPs may be prevented [13]. These significant reductions in CLABSIs, CAUTIs, and VAPs could potentially save between 15,000 and 45,000 lives annually [13]. Even mucosal barrier infections, a type of CLABSI frequently involving translocation of bacteria in neutropenic oncology patients, may be potentially prevented using oral care bundles [14–16].

While the potential to reduce morbidity and mortality are the main motivating factors for HAI prevention, avoidance of high attributable costs can also motivate organizations to invest in prevention. Estimates of the annual HAI costs in the US range from $9.8 to $45 billion [17, 18]. Pediatric patients who develop a CLABSI cost the healthcare system $33,000–55,000 per infection, with an increased length of stay of 9–19 days [19–21]. Attributable cost and length of stay for CLABSIs in neonates is estimated at $90,000 and 31.5 additional hospital days, respectively [19]. The direct attributable cost of a pediatric VAP is estimated at $51,000, and the direct attributable cost of a CAUTI is estimated at $7200 [22–24].

The bundle concept

The concept of a prevention "bundle" to reduce HAIs was born at the turn of the millennium out of a cooperative approach between two groups, the Institute for Healthcare Improvement (IHI) and the Voluntary Hospital Association [24]. Recognizing the need to improve patient care in the critical care setting, these groups formed a collaborative among 13 hospitals to develop processes to improve multiple aspects of critical care. This collaboration found its greatest success in the care of patients receiving mechanical ventilation and those with central venous catheters [24]. They grouped together the most clinically accepted best practices and evidence-based interventions for ventilator and central line care, terming them "bundles" [25–27]. According to the IHI, a bundle is "a small set of evidence-based interventions for a defined patient segment/population and care setting that, when implemented together, will result in significantly better outcomes than when implemented individually" [24]. In addition, effective bundles typically have the following characteristics: [24, 28]

- The bundle has few (typically three to five) interventions, making it practical but not comprehensive.
- Each element has strong evidence, often supported by a randomized controlled trial and already accepted with consensus among providers.
- Each bundle element is independent so that if one element is not performed, it will not impede the completion of other elements.

- A multidisciplinary team develops the bundle and refines it through standardized improvement processes, research, and the experience of users.
- Bundle elements should be more descriptive, rather than obligatory, allowing for site-specific customization and appropriate clinical judgment.
- A bundle is only complete if each individual element is completed. Compliance should be measured using an all-or-none measurement.

Compliance with bundle elements requires healthcare staff cooperation, but leads to improved performance compared to improvements achieved when focus is placed on only an individual bundle element [24]. The IHI's white paper on bundles gives the following example: when each of five bundle elements is delivered at 90% compliance (which may initially seem fairly acceptable), the entire bundle is actually delivered at 59% compliance (90% × 90% × 90% × 90% × 90%) [24]. In reality, initial rates of all-or-none compliance are often much lower than the above example, which can be alarming to healthcare workers, patients, and families. In turn, this prompts awareness that maximal care is not being delivered and frequently motivates healthcare teams toward multidisciplinary, cooperative action to improve their processes [24]. However, it is important to note that there is scant research indicating that bundles work on their own as an isolated strategy [28]. Rather, bundles should be used as a tool within a comprehensive quality improvement strategy.

Over time, the IHI has published additional bundles for sepsis resuscitation, elective obstetrical induction, and obstetrical augmentation [29, 30]. SPS has published bundles for the prevention of multiple other non-infectious pediatric hospital acquired harms as well [6••]. As healthcare bundles gained increasing acceptance as valuable tools in the adult population, providers began to advocate for the use of bundles in neonatal and pediatric intensive care units [28]. When compared to adults, pediatric patients have different anatomy, physiology, disease states, and treatment plans [28]. These differences further underscore the need for studying pediatric-specific bundle elements and implementation strategies.

Bundle use in neonates and children

The impact of CLABSI bundles has been studied most extensively in children's hospitals. Many have demonstrated reductions in CLABSI rates after the implementation of bundles in PICUs [28, 31, 32] and neonatal intensive care units (NICUs) [28, 31–39]. Pediatric CLABSI insertion (Table 1) and CLABSI care and maintenance (Table 2) bundles from reputable sources are summarized in this chapter. The Association for Vascular Access, Infusion Nurses Society, National Association of Neonatal Nurses, and others have published additional CLABSI prevention guidelines [43, 44•, 45]. IHI, Society for Healthcare Epidemiology of America, and SPS have published pediatric-specific strategies for VAP prevention (Table 3) [6••, 48, 50•]. Similarly, there is a growing body of evidence for the effectiveness of bundles for VAP reduction in PICUs [28, 31, 32, 51, 52] and NICU [28, 31, 32, 53, 54] setting. While there have been fewer studies on the efficacy of CAUTI insertion (Table 4) and care

Table 1. Central line insertion bundle

Element	SPS [6••]	IHI [25]	CDC [40, 41]
Hand hygiene	Yes, before and after palpating insertion sites, before and after inserting an intravascular catheter.	Yes	Yes
Chlorhexidine (CHG) scrub	Yes, prepare clean skin with a 0.5% CHG preparation with alcohol before CVC insertion and during dressing changes. If contraindication to CHG, tincture of iodine, an iodophor, or 70% alcohol can be used. No antibiotic ointment or cream on insertion site should be used, except with dialysis catheters.	CHG skin antisepsis	Adhere to aseptic technique. Perform skin antisepsis with >0.5% CHG with alcohol.
Insertion tray or cart	Prepackaged or filled insertion cart, tray, or box that contains all the necessary supplies.		
Checklist	Insertion checklist with staff empowerment to halt any non-emergent procedure.		
Full sterile barrier	Yes, including the use of a cap, mask, sterile gown, sterile gloves, and sterile full body drape for the insertion of central lines or guidewire exchange.	Maximal barrier precautions	Maximal sterile barrier precautions (i.e., mask, cap, gown, sterile gloves, and sterile full-body drape).
Training	All inserters should undergo insertion training.		
Optimal catheter site selection		Avoidance of femoral vein for adults	Choose the best site to minimize infections and mechanical complications. Avoid the femoral site in adult patients.

and maintenance bundles (Table 5) in children, a quality improvement strategy utilizing a bundle approach found a 50% reduction in CAUTI rates in PICU patients [55]. The rate of HAIs does seem to be decreasing, due to implementation of these bundles along with other quality improvement efforts. Of note, a Centers for Disease Control (CDC) dataset including 174 hospitals and excluding critical access, long-term care, and cancer hospitals noted a 62% reduction in CLABSIs, 76% reduction in VAP, and unchanged rate of CAUTI over the 2007–2012 study period [56]. Some note that the evidence for bundle elements in NICU and PICU patients is not as robust as in the adult population, leading to variety in bundle elements depending on the organization [32].

There is significant variation between organizations on contents of various pediatric bundles and in the number of bundle components. Nearly all focus on avoiding device utilization unless absolutely necessary, device removal when no longer absolutely essential, and minimizing entry into the device. However, despite these weaknesses, the most difficult part of quality improvement science is translation to the bedside. Thus, hardwiring processes set up for success,

Table 2. Central line care & maintenance bundle

Element	SPS [6••]	APIC [42] and CDC [40, 41]
Daily discussion of necessity and removal of unnecessary lines	Daily discussion of the necessity, functionality, and utilization including team	Yes. Perform daily audits to assess whether each central line is still needed. The indication for the line is documented daily.
Dressing maintenance	Regular assessment of dressing to assure clean, dry, and occlusive. Replace catheter site dressing if the dressing becomes damp, loosened, or soiled. Replace dressings used on short-term central venous catheter sites every 2 days for gauze dressings and at least every 7 days for transparent dressings.	Cover the site with sterile gauze or sterile, transparent, semipermeable dressings. Wash hands with conventional soap and water or with an alcohol-based hand rub prior to and after accessing the dressing. Dressing should be clean, dry, and intact.
Standardized access procedure	Hand hygiene. Disinfect cap before all line entries by scrubbing with an appropriate antiseptic and accessing the port only with sterile devices. 15 second alcohol scrub and allow to dry or an alcohol/ CHG-containing product per manufacturer's recommendations. Document date dressing was changed or is due for change. Sterile gloves are used for needle access for all implanted permanent central lines.	Handle and maintain central lines appropriately. Wash hands with conventional soap and water or with an alcohol-based hand rub prior to and after accessing the central line or needleless access device. Access catheters only with sterile devices. Catheter hubs, needleless connectors, and injection ports are to be cleaned before accessing the catheter with CHG, iodine, or 70% alcohol using a twisting motion for at least 15 s.
Standardized dressing change procedures/timing	Scrub skin around site with CHG for 30 s (2 min for femoral site) followed by complete drying (Note: institutional preference for CHG use for infant <2 months of age). Document date dressing was changed or is due for change. Sterile gloves are used for dressing changes.	Replace dressings that are wet, soiled, or dislodged. Perform dressing changes under aseptic technique using clean or sterile gloves. If gauze dressing is used, change every 48 h. Transparent dressing is changed at least every 7 days.
Standardized cap change procedures/timing	When the hub of the catheter or insertion site is exposed, wear a mask (all providers and assistants), shield patient's face, endotracheal tube, or tracheostomy with a mask or drape. Sterile gloves are used for cap changes. Document date cap was changed or is due for change.	
Standardized tubing change procedures/timing	Change crystalloid tubing no more frequently than every 72 h. Change tubing used to administer blood products every 24 h or more frequently per institutional standard. Change tubing used for lipid infusions every 24 h. Sterile gloves are used for tubing changes. Document date tubing was changed or is due for change.	
Multidisciplinary review of all CLABSIs	In-depth review of all identified CLABSIs should be performed with multidisciplinary involvement and the process changed if needed (recommended).	

Table 2. (Continued)

Element	SPS [6••]	APIC [42] and CDC [40, 41]
CHG-impregnated sponge or dressing	If sponge used, it should be oriented correctly and changed at same time as dressing. (optional)	
Securement device		If possible, suture-free securement device is used and changed with transparent dressing (optional).
CHG bathing	Daily (recommended)	Daily bath is performed with 2% CHG (optional).
Linen changes	Daily (recommended)	

including the use of clinical decision support and studying workflow, are key to this translation to the bedside.

Beyond the bundle

Certainly hand hygiene and personal protective equipment, as well as meticulous care and maintenance of invasive devices, are the cornerstones of infection prevention. In addition to bundle utilization, some institutions have implemented additional strategies in an effort to prevent HAIs. "No touch" methods such as ultraviolet light (UV-C or UV-xenon) and hydrogen peroxide (vapor or aerosolized) have been used as an additional room cleaning strategy and have promising results in the reduction of multidrug resistant organisms such as *Clostridium difficile*, methicillin-resistant *Staphylococcus aureus* (MRSA), and vancomycin-resistant enterococcus (VRE) [57]. Self-disinfecting surfaces such as plating with copper, silver, or triclosan on bedrails and other high touch surfaces have also been used with promising results [58]. Copper plating has been shown to reduce bacterial contamination of surfaces in several studies, and one study demonstrated reduction in HAIs [59–61]. Ethanol locks have been used to prevent CLABSI, though mostly as a secondary prevention strategy

Table 3. VAP prevention bundle

Element	SPS [6••]	IHI [27]	APIC [42]	CDC [46]
Aseptic technique	Perform hand hygiene immediately before and after insertion or any manipulation of the catheter device or site. Use sterile gloves, drape, sponges, and appropriate antiseptic or sterile solution for peri-urethral cleaning, and a single packet of lubricant jelly for insertion.	Yes	Yes	Yes. Only persons properly trained in aseptic insertion are given this responsibility.
Avoid unnecessary catheters	Yes. Consider having written clinical indications.	Yes	Yes	Insert catheters only for appropriate indications. Avoid catheters in inpatients or nursing home residents for management of continence.

Table 4. Indwelling urinary catheter insertion bundle

Element	SPS [6••]	IHI [27]	APIC [47]	CDC [46]
Maintain a closed drainage system	If breaks in aseptic technique, disconnection, or leakage occur, replace the catheter and collecting system using aseptic technique and sterile equipment.	Maintain sterile continuously closed drainage system.	Tamper evident seal is intact.	Maintain closed drainage system.
Maintain hygiene	Perform perineal hygiene at minimum daily.		Daily meatal hygiene performed with soap and water.	
Bag or collection container height	Keep bag below level of bladder. Do not rest bag on floor.			
Maintain unobstructed flow of urine	Keep the catheter and collecting tube free from kinking.	Maintain unobstructed flow.	Maintain unobstructed flow.	Maintain unobstructed flow.
Remove catheter when no longer needed	Review necessity daily. Document indication daily.	Review necessity daily.	Daily documented assessment of need. Providers decide to remove or continue each day based on indication.	Remove catheters from post-operative patients as soon as possible, preferably within 24 h.
Individual collection containers		Empty collection bag regularly using a separate collecting container for each patient.	Drainage bag emptied using clean container.	
Secure catheter	Use securement device (recommended).	Keep properly secured to prevent movement and urethral traction.	Securement device in place.	
Training				Only persons properly trained in care and maintenance are given this responsibility.

particularly in children with intestinal failure [62, 63]. Ethanol acts by removing biofilm and also through bactericidal and fungicidal properties. Resistance has

Table 5. VIndwelling urinary catheter care & maintenance bundle

Element	SPS [6••]	IHI [48] and APIC [49]	SHEA [50•]
Readiness to extubate and sedation interruption	Assess readiness to extubate and document at least daily.	Daily interruption of sedation not recommended in children due to high risk of unplanned extubation. Include daily assessment of readiness to extubate in rounds or using a checklist.	Recommend non-invasive ventilation. Minimize duration of mechanical ventilation. Assess readiness to extubate daily using spontaneous breathing trials. Preterm neonates: Manage patients without sedation when possible. Do not recommend daily sedation interruption or spontaneous breathing trials.
Head of bed elevation	Elevate head of bed to 30–45° (non-neonates). Consider the use of a visual measuring device (e.g. protractor painted on bedside) to ensure the angle is correct.	Elevation of the head of the bed to between 30 and 45°. Use 15–30° for neonates and 30–45° for infants or above.	Elevation of the head of the bed to between 30 and 45°. Preterm neonates: Alternate positioning may include lateral recumbent positioning or reverse Trendelenburg.
Minimize disruption of the circuit	Inspect ventilator circuit for gross contamination and/or condensation daily (recommended: at least every 8h). Drain condensation. Only change circuit for gross contamination or when visibly soiled. Avoid changing ventilator circuit on routine basis.	Circuit changes should take place only when it is visibly soiled or mechanically malfunctioning. Change in-line suction catheter systems only when soiled or otherwise indicated. Drain water away every 2–4 h away from the patient and prior to repositioning. Consider heated vent circuits which decrease the occurrence of condensate. Use meticulous hand hygiene before and after contact with ventilator circuits	Circuit changes should take place only when it is visibly soiled or mechanically malfunctioning. Preterm neonates: Recommend closed in-line suction. Prevent condensate from reaching patient.
Oral care	Perform oral hygiene minimally every 12 h.	Daily oral care with CHG	Provide regular oral care, but antiseptics may not have impact. Preterm neonates: Oral care with sterile water. Do not recommend antiseptics.
Peptic ulcer disease prophylaxis		Yes, as appropriate for the child's age and condition.	Not recommended
Deep venous thrombosis prophylaxis		Yes, unless contraindicated and as appropriate for the child's age and condition.	Not recommended
Cuffed endotracheal tubes			For non-neonates, recommend cuffed endotracheal tubes with subglottic secretion

Table 5. (Continued)

Element	SPS [6••]	IHI [48] and APIC [49]	SHEA [50•]
			drainage ports for older pediatric patients expected to require >48–72 h on ventilator.

not been documented with the use of ethanol locks, and it is fairly inexpensive [64]. Drawbacks include the requirement for dwell time (i.e., the line cannot be continuously infusing), possible increased risk of breakage or thrombosis, potential toxicity in small infants, and the inability to use with a polyurethane catheter. Continuous passive disinfection caps have also been studied extensively as a CLABSI prevention strategy, and a meta-analysis did demonstrate reduction in CLABSI rates with the use of barrier caps [65]. Most experts would suggest that the needleless connector should still be scrubbed after the removal of the device cap in order to maximize aseptic technique.

One of the most extensively adopted strategies for HAI prevention has been the utilization of chlorhexidine (CHG) bathing. This broad-spectrum topical antiseptic is effective against a wide spectrum of organisms, and when used for bathing, its antiseptic effect is known to last up to 24 h after it is applied. CHG bathing has been found to reduce CLABSIs, prevalence of multidrug resistant organism colonization (ex: MRSA, VRE), CAUTIs, blood culture contamination, clostridium difficile infection, and surgical site infections when used preoperatively [66–73]. Historically, there were concerns about CHG causing neurotoxicity in infants similarly to hexachlorophene, a chemically distinct compound that caused neurotoxicity in infants in the 1970s. However to date, there is no evidence that CHG accumulates in the blood of children even after repeated exposure [74]. Since there are topical products such as lotions that contain compounds known to inhibit CHG activity, compatible skin products must be chosen with care. Several studies examined the impact on nursing workload when using CHG bathing protocols and found CHG bathing preferable to soap and water baths [73, 75]. In fact, nurses continued the use of CHG baths after the studies were over; the bath took ~4–5 min to complete, and staff were satisfied with the method and effectiveness on patients [73, 75]. The data to support CHG bathing in critically ill children in Milstone's large study demonstrating lower incidence of bacteremia did include bone marrow transplant and other immunocompromised patients [76]. CHG bathing has also been studied in non-critically ill pediatric patients [66]. Caregivers should avoid applying CHG to broken skin, above the neck, or on mucous membranes. Antimicrobial resistance has not been noted with the use of CHG bathing in children; however, CHG bathing has been associated with development of multidrug resistant gram negative bacterial infections in adult stem cell transplant patients [77, 78]. The SCRUB (scrubbing with chlorhexidine reduces unwanted bacteria) trial was a landmark study in pediatrics which was an unmasked, cluster-randomized,

crossover trial in ten PICUs at five hospitals in the USA evaluating the use of CHG baths in nearly 5000 admissions [76]. CHG was well tolerated (1% of children developed a minor skin reaction, though there is a risk of a more severe reaction). Critically ill children who received daily CHG baths had a lower incidence of bacteremia compared with the control group getting soap and water baths (3.2 vs 4.9 per 1000 patient days, $p = 0.044$, representing a 36% lower risk of bacteremia). There was a non-statistically significant lower mortality rate in CHG group [76]. SPS recommends daily CHG bathing in children with a central venous line [6••].

In conclusion, while elements may be added or removed from HAI prevention bundles with additional research, it is likely that most of the success described has occurred after culture change and reliable institutional implementation of bundles. Success will additionally rely on intangibles such as patient and family engagement, financial commitment to resources needed, intuitive clinical decision support, serious engagement from the bedside to senior leadership, use of high reliability principles, interdisciplinary teamwork and communication, and a robust culture of safety [79–81].

Compliance with Ethical Standards

Conflict of Interest

Elizabeth H. Mack declares that she has no conflict of interest.
Christopher T. Stem declares that he has no conflict of interest.

Human and animal rights and informed consent

This article does not contain any studies with human or animal subjects performed by any of the authors.

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- • Of importance
- •• Of major importance

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