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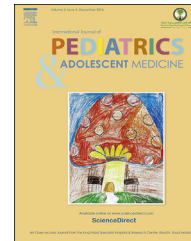


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Review Article

Essentials of infection prevention in the pediatric population



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Abstract Application of infection prevention and control (IP&C) measures is synonymous with safety, quality, resource saving, and the rights of all patients, staff and visitors. An extensive literature review was undertaken to identify key IP&C measures that address pediatric-specific requirements, taking into account age-related factors, diseases that occur most frequently among pediatric populations, and the important role of the caregiver in prevention and disease transmission. IP&C initiatives that target and incorporate both human (intrinsic) and environmental (extrinsic) sources of infection are population specific and guide practices and provide safe caring environments when used appropriately.

Categories of care specifically geared to the pediatric age-group (0–14 years) are divided into two categories: *within-the-healthcare system* and *outside-of-the-healthcare* setting. By taking into account the child's developmental age; physiological, psycho-social and immunological development; differing impacts on the body's natural defense mechanisms, including procedural, device type and length of utilization; and availability of specific technologies and disciplines, the caregiver IP&C strategies can be developed and tailored to address specific needs. Within-the-healthcare setting strategies focus on surveillance, standard and transmission-based precautions, the immune system, age-related factors, institutional regulations, the family and visitation. Outside the healthcare setting preventative and protective measures are vital for providing maximum and comprehensive care. Care provided within and outside the healthcare setting can either be independent of each other or work together to maximize the health and safety of the child.

This review article highlights the importance of IP&C knowledge, need for strict adherence to approved standards, and need for auditing compliance to achieve the ultimate goal of providing safe, quality care as well as an infection-free environment.

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1. Introduction

Infections within any healthcare institution can be avoidable when dealt with appropriately. If infections are ignored or proactive strategies are not applied, healthcare-associated infections (HAIs) will result in patient morbidity, mortality, and additional resource use. Healthcare workers (HCWs), families, visitors and contractors are susceptible to health and safety issues when infection prevention & control (IP&C) measures do not incorporate an all-inclusive approach [1,2].

HAIs, including device related, surgical site infections (SSIs), transmissible/infectious diseases or pathogens of concern, including viral, bacterial, fungal, and multidrug resistant organisms (MDROs), do not discriminate between age, gender, religion, or ethnicity. If stringent measures are not applied, the pediatric population is at equal, if not at higher, risk of infection or injury compared to adolescents and/or adults. The pediatric/child population, as defined in this paper, include those children between (0–14) years of age [3]. This includes pre-term and term newborns (less than 6 months of age), as well as infants, toddlers, children and pre-teens (6 months of age to 14 years). This paper does not directly discuss issues related to adolescents (15–18 years) or adults (18 years and older).

An extensive literature review was undertaken to identify key IP&C areas that target pediatric-specific populations. The aim was to identify those IP&C related measures that take into account a child's developmental age; physiological, psycho-social and immunological development; risk of HAIs by compromised natural defense mechanisms, including procedural, device type and length of utilization causes; availability of specific technologies and disciplines; and the role the caregiver in providing a safe and infection-free environment [4]. Caregivers in this paper are defined as either familial (parent, relative, or guardian) or HCWs who provide direct or indirect care.

The device-associated (DA) infection rates reported in the National Healthcare Safety Network (NHSN) – 2013 report suggested that neonates (well-baby, step-down and neonatal intensive care units) have a 1.13/1000 device-days (DDs) infection rate, while the combined rate for children admitted to wards in critical care, step-down, and receiving hematology/oncology and hematopoietic stem cell transplants is 1.46/1000 DD [5]. Combining the provided pediatric-specific rates in the NHSN report, the findings suggest that the highest DA infections occur among hematology/oncology (2.12/1000 DDs) and hematopoietic stem cell transplant (2.3/1000 DDs) patients, with a combined rate of 2.14/1000 DDs. This compares to 1.31/1000 DDs for all other pediatric areas combined.

These rates support the observation that severely immunocompromised hospitalized patients are at the highest risk of DA HAIs. In addition, differences in infection rates, sites, and pathogen distributions have been noted to differ depending on susceptibility, immune status, age-group, and setting. A mortality rate of 3% has been attributed to blood stream infections (BSIs) within the pediatric population, with a mortality rate as high as 11% in neonates alone, particularly in those with very low-birth weights [5–7].

To address the high rate of infections and need for corrective measures, IP&C teams have evolved over the years and have become an essential component in all healthcare institutions. They provide a service to prevent, control, or reduce avoidable complications and infections, as well as promote safe practices for all patients and staff [8–10]. When issues are identified, the IP&C team intervenes to ensure that safe quality care is provided. Yet, IP&C strategies, for the most part, specifically target adult healthcare institutions [11]. Therefore, specialized programs need to be developed and tailored to meet the needs of the pediatric population, taking into account age-related factors that prevent the child from adhering to IP&C standards, as well as taking into account the impact that caregivers have on prevention and transmission. Without these specialized IP&C programs, there is a higher risk for developing HAIs due to developmental stages, social dependencies, differing diagnostic strategies, and immature immune systems [10,12,13].

This review article specifically evaluates IP&C and management practices for the pediatric population. We divided the health needs of the child into two categories: within-the-healthcare and outside-of-the-healthcare setting. Each setting has individual issues that have an impact on pathogen, disease or injury acquisition; modes of transmission; and implementation of IP&C strategies. Refer to Table 1 for a summary of risk and mitigation strategies.

2. Discussion

Children may not always display symptoms or have the ability to implement and understand strategies that are instigated for their own care, and therefore, diligent attention and supervision is required by caregivers. Ensuring family-centered care that incorporates appropriate hygiene, nutrition, and administration of vaccines (depending on strict age-defined schedules) provides a basis for ensuring growth, development, and an immune response that is age appropriate [7,14]. The forms of care provided within and outside the healthcare setting can either be independent of each other or work together to maximize the health and safety of the child. Although there are some similarities in IP&C strategies, pediatric populations cannot be considered miniature adults [3,15].

2.1. Within-the-healthcare setting

2.1.1. Institutional regulations

An IP&C program geared toward the needs of the pediatric population has to be robust, encompass the needs of all age groups, be supported by higher administration, and meet institutional strategic goals. If successful, it will meet growing international demands for medical care and increase capacities, waiting lists, patient flow, and the need for specialized and experienced staff in the field of pediatrics as well as improve efficiency, decision-making, and collaboration. A robust program will be able to protect and improve staff development, recruitment, retention, and promote internal and external relations.

Table 1 Infection prevention & control risk mitigation strategies.

Category	Risk	Mitigation strategy	References	
1	Institutional regulations	<ul style="list-style-type: none"> a. IP&C Program/policies/management support/evidence-based guidance b. Monitoring IP&C compliance c. KPIs for IP&C 	<ul style="list-style-type: none"> a. Robust program that meets institutional and governmental strategic goals based on the available best practice guidelines, recommendations and accredited bodies b. Monitoring of tailored IP&C policies that meet institutional and governmental goals c. Compliance monitoring of IP&C targeted processes (standard precautions, hand hygiene, transmission-based precautions) to identify practice gaps and implement corrective actions 	<ul style="list-style-type: none"> a. 1,9 b. 1,5,16–19 c. 5,20,21,28
2	Surveillance	<ul style="list-style-type: none"> a. IP&C team b. Planning surveillance for the pediatric population c. Monitoring surveillance outcomes 	<ul style="list-style-type: none"> a. Having a qualified IP&C team to undertake surveillance activities to detect trends/outbreaks/risks associated with healthcare interventions, and a tailored surveillance plan developed by undertaking an institutional risk assessment b. Enhanced IP&C measures and durations to reduce environmental contamination c. Use of appropriate resources, audits and measures to promote adherence to IP&C policies/procedures, decision-making and feedback outcomes to stakeholders including administrators 	<ul style="list-style-type: none"> a. 1,7,9,14,22 b. 1,9,14,22–26,2 c. 7,11,28
3	Immune deficiencies	<ul style="list-style-type: none"> a. Environmental impact on pediatric population b. Hygiene and the immune deficient pediatric patient c. Developmental stages and exposure to childhood diseases 	<ul style="list-style-type: none"> a. Maintain quality of care, including appropriate hygiene measures (intrinsic & extrinsic), minimizing or preventing contact with ill persons, use of non-live vaccinations b. Utilizing a protective environment to minimize potential environmental exposures through appropriate air handling, water quality, environmental surfaces and cleaning practices c. Early detection and initiation of transmission-based precautions (contact/droplet/airborne) 	<ul style="list-style-type: none"> a. 7,14,23,26–30,32,33 b. 28,32–34 c. 3,7,11,28
4	Caregivers	<ul style="list-style-type: none"> a. As a source of infection b. Poor compliance with hand hygiene c. Chain of infection d. Family-centered care and knowledge 	<ul style="list-style-type: none"> a. Appropriate immunization for caregivers (HCW and family members), implementation of specific HCW policies, maximization of immune status to childhood preventable diseases, appropriate staffing numbers and education b. Education of all caregivers (technique/reason why/when to) and adherence and compliance to policy c. Monitoring/compliance of hand, personal and environmental hygiene d. Strict policies/procedure on the family caregiver's role in the prevention of infections while visiting/staying, monitoring and education of family caregivers when lapses are identified 	<ul style="list-style-type: none"> a. 7,11,14,31,35–38 b. 3,7,16,28,38–41 c. 16,28 d. 7,11,14,26,28,30,35,37,42–44
5	Intensive care units for the neonate and child	<ul style="list-style-type: none"> a. HAIs and/or other complications b. Compliance 	<ul style="list-style-type: none"> a. Use bundles of care for VAP, CLABSI, CAUTI, and SSI (pediatric-specific) 	<ul style="list-style-type: none"> a. 5,27,46–48 b. 14,16,49

(continued on next page)

Table 1 (continued)

Category	Risk	Mitigation strategy	References	
6	Pediatric inpatient and outpatient settings	<p>a. Lack of awareness of basic hygiene needs</p> <p>b. Environmental consideration</p>	<p>a. Reliant on caregivers supervisory skills and knowledge for day-to-day care, including all hygiene needs and bodily functions, education and reinforcement required to ensure pediatric safety</p> <p>b. Limit toys/type of toys available to those that are cleanable (non-plush), give dedicated toys whenever possible, instigate cleaning of toys between patients which is documented and monitored</p>	<p>a. 9,14,27,50</p> <p>b. 7,27,51–54</p>
7	Respiratory infections	<p>a. Identification</p> <p>b. Vaccination</p>	<p>a. Early and accurate identification of infectious patients incorporates early isolation, treatment, reduced spread using segregation of symptomatic patients/appropriate use of PPE</p> <p>b. Appropriate vaccination where applicable</p>	<p>a. 11,29,31</p> <p>b. 27</p>
8	Gastrointestinal infections	<p>a. Hygiene</p> <p>b. Environmental contamination</p>	<p>a. Reduce fecal-oral spread by implementing appropriate IP&C measures (hand hygiene especially before/after handling diapers/cleaning procedures/use of PPE/use of transmission-based precautions)</p> <p>b. Strict use of IP&C practices (contact transmission-based precautions/hand hygiene) environmental cleaning (may include enhanced cleaning practices or the use of disinfectants)</p>	<p>a. 7,14,16,24</p> <p>b. 7,14,24,27</p>
9	Multidrug resistant organisms	<p>a. Controlling spread</p>	<p>a. Use of preventative IP&C practices: hand hygiene, use of PPE, reducing and controlling environmental contamination, education of caregivers, decolonization and antimicrobial controls</p>	<p>a. 9,27,47,57–59</p>
10	Preventative and protective measures outside the healthcare setting	<p>a. Unsafe environment</p>	<p>a. Prevention of injury and providing a safe environment includes: all aspects of safety (home/water/road/slips/trips/falls/preventing abusive situations) as well as reducing the risk of infection by maintain cleanliness of environment (including toys), reduce exposure to childhood diseases, limit contact with animals and providing appropriate age-related immunizations</p>	<p>a. 7,27,28,32,54,62,66–68</p>

Without higher management oversight and support, an IP&C program cannot function, meet its objectives or ensure maximum compliance to policies and recommendations [9]. Policies and recommendations that are evidence-based and utilize well recognized national and international authorities and directives (such as governmental ministries, recognized associations e.g., US-Centers of Disease Control and Prevention [US-CDC], European Center for Disease Prevention and Control [ECDC], Department of Health: Disease Control and Prevention in Australia, World Health Organization [WHO]), as well as

approved accreditation bodies (e.g., governmental and private), provide reputable and evidence-based information [1]. Although no specific regulations were found in the reviewed literature for inclusion in this paper, specific guidelines geared toward the pediatric population will, if implemented correctly, have institutional and community-wide benefits.

Monitoring compliance and performance of HCWs is a well-reported strategy for preventing the transmission of HAIs [1,16–18]. This enables actions to be undertaken against the institution's documented policies and/or

procedures and identifies issues that can be easily recognized and rectified [1,19]. Although monitoring compliance is a well-known concept in relation to HALs (outcome indicators) [5], no specific key performance indicator(s) (KPI) for IP&C practices (process indicators) have been established and approved internationally [20,21]. The authors believe that to ensure compliance with basic IP&C principles (target processes such as hand hygiene, standard precautions and transmission-based precautions), robust KPIs need to be monitored, focusing on targeted processes. The results and recommendations need to be reported to key stakeholders, including higher management, which will subsequently help to reduce HALs by ensuring that all HCWs are held responsible and accountable for their practice.

2.1.2. Surveillance

Undertaking surveillance in pediatrics patients, including DA, SSI, dialysis-events (DEs), rates of MDROs, gastrointestinal, and respiratory illnesses, is important to provide a basis for action and decision-making. Furthermore, surveillance facilitates support and vital resources to be channeled into appropriate areas. This includes staffing numbers and levels of experience, early detection and intervention in outbreak situations [7], environmental controls, adequate supplies, and programs for education. The lack of a functional surveillance program may ultimately result in missed trends and underdetermine the magnitude of HALs and risks associated with healthcare procedures [22]. It is vital that each healthcare facility determines the type and frequency of surveillance required for their patient population(s). This can be achieved by undertaking an IP&C risk assessment [1,9,14].

Surveillance, whether it is targeted, total-house, or a combination of the two, is of paramount importance for identifying institutional problems, including outbreaks, as well as for directing initiatives [22]. Outbreaks of infectious pathogens can result in patient morbidity/mortality, environmental contamination, and/or HCW absenteeism. Implementation of appropriate measures to minimize or prevent transmission is of paramount importance. It is well documented that pediatric and the immunocompromised shed viruses for longer periods of time [23–27]. This alters and increases the potential duration of the preventative measures required and risks involved. Cohorting can be an effective preventative strategy in selected circumstances. It may be required during outbreaks when there is limited resources and increased occupancy. Consultation with experts in the IP&C and Infectious Disease fields is vital to ensure appropriate utilization of resources in decision-making and promoting adherence with standard and transmission-based precautions (contact, droplet or airborne) [7,11,28].

2.1.3. Immune deficiencies

Within-the-healthcare setting, patients are placed at increased risk based on their compromised or naive immune systems/diseases or due to neutropenia [23,26]. Certain diseases increase the risk of infections within-the-hospital setting by their nature alone. Those diseases that cause immunodeficiency or under-developed immune systems include certain syndromes, cancers, transplants, certain lung diseases, immaturity, and/or very low-birth weights of the newborn [7,23,27,29].

Maintaining quality of care for the immunocompromised population includes routine practices, such as hand, environmental and personal hygiene measures; nutrition; dental care; minimizing/preventing contact with ill persons; using non-live vaccines, among other basic measures [30–32]. A physical protective environment used with this patient population encompasses air, water, and structural factors that reduce pathogenic materials in the environment [7,14,30].

Environmental protection consists of positive air pressure; air hepa-filtration with a sufficient number of air changes per hour (ACH); absence of plants, carpets or difficult to clean surfaces, and windows; and gaps that are well-sealed to external elements. There needs to be routine and scheduled maintenance, as well as cleaning with a regulatory environmental protection agency (EPA) approved disinfectant, to ensure that the environment and equipment is free, at least to a minimal degree, of dust and pathogens [28,32–34]. This includes the cleaning of medical and non-medical equipment prior to use. Water sources and transport systems, such as taps, showers, and ice machines, need to have frequent and routine maintenance and be tested for waterborne pathogens [14,28,32,33].

Whether it is a within-the-healthcare or outside-of-the-healthcare setting, the stages of development and exposure to childhood illnesses have an impact on a child's risk of acquiring an infection [3,7,11,28]. Breaking the chain of infection by utilizing standard and transmission-based precautions that are geared toward specific pathogen transmissibility ensures that control measures are individually tailored. The key is early detection and initiation of isolation or segregation with strict adherence [11].

2.1.4. Caregivers

Caregivers themselves can be a source of infection for a child [35,36]. Close physical contact by HCWs or family caregivers provide a medium for transmission [7,11,31,35,37]. Poor IP&C practices, as discussed above, can be compounded by understaffing, poor knowledge and/or compliance, and overcrowding [11,14]. To reduce risk, caregivers should be appropriately immunized with available vaccines, and non-immune personnel to childhood diseases should not provide direct care to an infectious patient as they themselves are at risk of disease acquisition and can contribute to subsequent spread [29–31,38]. This is in compliance with standard and transmission-based precautions, which are a well-researched practices that break the chain of infection [28].

Hand hygiene by all direct and indirect caregivers has clear documented support in the reduction of HALs [16,39,40]. Ensuring that all caregivers have the knowledge, education, skills, and physical resources to perform appropriate hand hygiene techniques and to know in which instances they should be applied (such as the WHO 5 Moments of Hand Hygiene) is vital and well-researched [3,7,16,38,40,41].

The family is a core component and an active part of the care-team in family-centered healthcare. Knowledge and compliance by family caregivers may be a challenge, thus it is important to recognize them as a potential source for infection spread. There are documented cases of family members and/or visitors being the source of infection

[30,37]. Strict policies and/or guidelines are required in addition to education activities and materials for parents/guardians/relatives staying or visiting a child while in the healthcare setting [9,11,26,42,43]. As a solution, education and monitoring of family and visitors is required and needs to be strongly reinforced [26,35,44]. Instructions to abide by set rules and regulations to prevent or reduce the acquisition and spread of pathogens is required. This includes adherence to hand hygiene, respiratory and cough etiquette, reducing socialization with other parents/patients, limiting visiting numbers, and limiting contact with ill or symptomatic persons [7,11,14,28,42–44].

2.1.4.1. Intensive care units for the neonate and child. Premature infants may have immature defense mechanisms (including skin, gastrointestinal systems, lungs, etc.) or be born with severe medical conditions. These predispose neonates to HAIs and/or complications [14,45]. Invasive devices, treatments, supports, or new technologies used in neonatal intensive care units (NICU) have, in modern times, prolonged the life of these pre-term infants, but each treatment modality has consequences and risk factors [45]. They independently increase the risk of morbidity and mortality as well as potential acquisition of pathogens. For this reason, extensive research concentrating on birthweight as a risk factor has centered on infection rates within NICUs [5,46].

Strategies to prevent HAIs within the NICU should include bundles of care that are specifically created for this patient population [47]. Device related infections in the neonatal population include central and peripheral lines, as well as ventilator associated pneumonia (VAP). Due to limited use of foley catheters in the NICU, there is no benchmark or data available for catheter-associated urinary tract infections (CAUTI), but DA urinary tract infections can be a concern in this high-risk patient population [5].

What separates pediatric intensive care units (PICUs) from NICUs is that the HCWs in a PICU need to be able to manage a variety of childhood and infectious diseases. Children of all ages are admitted into a PICU for multiple reasons, which include both immune-competent and immunocompromised statuses [27,48]. Most, if not all, patients in PICUs have invasive devices inserted or have undergone invasive procedures (e.g., surgical) that require preventative measures. There needs to be individualized and unique considerations taken into account for the pediatric population, such as developmental age, levels of mobility, understanding, and appropriate products that are age-related, i.e., chlorhexidine gluconate (CHG) [27].

Adherence to bundles of care for central lines, VAP, CAUTI and SSI is paramount [5,27,46]. Each bundle component is vitally important and encompasses education and compliance [14,49]. It is often difficult to determine which element has the greatest influence, and it would be unethical to undertake a study to evaluate this observation.

2.1.5. Pediatric inpatient and outpatient clinic settings

The younger the child, the less educated or aware and compliant to basic hygiene practices they are. This relates to both physical and emotional stages of growth. Basic hygiene practices refer to hand, respiratory, body, clothing

and environmental cleanliness. Young infants and children have a tendency to drool, have incontinence, and undertake frequent mouthing of hands and objects regardless of their level of cleanliness [14]. These children are reliant on the adult caregiver's supervisory skills to ensure that all required safety, quality, and IP&C strategies are applied in their day-to-day care [27]. This includes feeding (i.e., food quality, quantity and preparation), toilet use and diapering, bathing and hand washing, and sharing of personal items, such as combs, brushes, coats, hats, toys, and shoes [9,50]. Older children are more able to care for themselves to a certain degree and make conscious decisions regarding their care, though they are still reliant on adults to guide them and ensure their ultimate safety.

Environmental considerations in inpatient and outpatient settings often include the use of toys, but toys can be a vehicle for pathogen transmission [27]. The use of toys within healthcare include therapeutic, recreational and educational purposes [7,27]; use in waiting areas and play rooms or classrooms [51–53]. Of particular concern are toys that cannot be cleaned easily, are non-immersible, or due to/or lack of internal processes, are not on a cleaning schedule. Research supports that within healthcare settings, plush (soft) toys that are shared are of a higher risk for vector transmission [53,54]. Strategies must include the use of non-plush toys (unless new and dedicated), dedicated toys where possible if they cannot be cleaned easily, cleaning between patients, or applying a strict cleaning regime that is documented and monitored [27,53,54].

2.1.6. Respiratory infections

Respiratory infections, both upper and lower, account for the most common-occurring pediatric illness of infectious nature [29,55]. Viral infections include influenza, respiratory syncytial virus (RSV), rhinovirus, parainfluenza, human meta-pneumovirus, adenovirus, bocavirus, and coronaviruses. Identification of contagious pathogens that cause respiratory infections has improved with diagnostic and rapid testing methods and, subsequently, has had an impact on early identification, isolation, and treatment [11].

Early and accurate identification of symptomatic children results in targeting early isolation, preventative measures, and improved compliance practices to reduce the risk of spread. This includes segregation, use of personal protective equipment (PPE), and promotion of available vaccines. Early identification of pathogens, implementation of appropriate droplet and contact precautions, and strict environmental and equipment cleaning prevent further transmission and potential outbreaks from occurring [29,31].

Vaccination plays a strong role in preventing respiratory and other serious infections in the pediatric population. Since the introduction of *Haemophilus influenzae type B*, *Streptococcus pneumoniae*, pertussis, and *Neisseria meningitidis*, the rates of infections due to these diseases have declined significantly [27].

2.1.7. Gastrointestinal infections

Gastrointestinal or diarrheal illnesses of a viral nature are often referred to as enteric infections and are common among the pediatric population. Enteric infections that commonly occur in children include Norovirus,

enteric Adenovirus serotypes, Rotavirus, Enterovirus, and *Clostridium difficile* [7]. Non-viral enteric organisms of concern in children include MDROs, such as vancomycin resistant enterococcus (VRE); bacteria, such as salmonella and shigellosis; and parasites, such as cryptosporidium and pin-worm. These are often the source of fecal-oral spread due to poor hygienic measures among children and/or caregivers [14]. Prevention for this group of infectious pathogens heavily relies on the education of caregivers and, if possible, the child on key measures, such as hand hygiene, handling of soiled items (diaper, clothing, and equipment, etc.), and environmental cleaning with disinfectants to remove the presence of organisms [7,24].

These and other organisms have the ability to remain viable in the environment for varying lengths of time, resulting in the occurrence of spread and, in some cases, extensive outbreaks [14,27]. When suspected or confirmed utilization of contact precautions is advisable, the patient should be in a single room if possible or, alternatively, cohort cases should room together upon advisement by an IP&C team. This is in addition to strict adherence to hand and environmental hygiene. In instances of outbreak, consultation and implementation of mitigating strategies to contain and resolve the situation is required.

2.1.8. Multidrug resistant organisms

The importance and impact of MDROs cannot be underestimated. These organisms pose a threat due to limited treatment options to first-line therapies [3]. There are strong concerns regarding the spread of MDROs within-the-healthcare setting. The pathogens of concern include methicillin resistant *Staphylococcus aureus* (MRSA) and VRE [27]. The concerns within-the-healthcare setting are in addition to the known occurrence of spread within the community, schools, and sports facilities [56]. At present, there is limited research about the attributable outcomes and effects of Gram-negative MDROs (in particular, beta-lactam resistant Gram-negative bacilli/extended-spectrum beta-lactamases [ESBLs] and carbapenem-resistant enterobacteriaceae [CRE]) within the pediatric population. This includes the areas of morbidity, mortality, length of stay (LOS), burden and cost to healthcare services [57].

As mentioned, the pediatric population heavily relies on direct hands-on-care. Therefore, MDRO pathogens can be spread easily via direct and indirect routes, are often difficult to treat and eradicate, are viable within the environment, and can remain on the skin whether as a result of colonization or as an infection for extended periods of time. Emphasizing preventive measures is important. These measures include hand hygiene, controlling environmental contamination, caregiver education, decolonization (if appropriate), appropriate PPE usage, and judicious antimicrobial controls [9,27,47,57–59]. However, little consensus exists regarding appropriate isolation precaution standards for ESBLs and CRE in the context of known prolonged shedding among the immunocompromised pediatric population [60].

2.1.9. Outside the healthcare setting

2.1.9.1. *Preventative and protective measures.* IP&C practices outside the healthcare setting mainly revolve

around ensuring child safety; preventing the acquisition of infections within the home, school or community; and preventing injuries that are both intentional and non-intentional. Guidance by caregivers is important in preparing the child during elective hospitalizations so that their physical, immunological and mental status is optimal in preparing them to cope with the healthcare setting [7]. In addition, circumstances resulting in an unexpected need for hospitalization may contribute to compromised states, which subsequently could lead to HAIs.

Providing a safe environment outside the healthcare setting includes addressing the need for appropriate nutrition, clothing, shelter and education; minimizing the risk of injuries, such as falls, suffocation or choking; ingestion or absorption of poisons; scalding or burns; electrocution; wearing of seat belts; safe play activities, including playgrounds, toys, and water activities that increase the risk of drowning (bathing or sports related); handling; care and exposure to pets and/or other animals with risks for bites and scratches; or exposure to abusive or neglectful situations, both physical and/or emotional [61–65].

Safety measures take into account the child's age, developmental physical and cognitive abilities, individual characteristics, degrees of dependence, activities, and potential exposure to possible hazards and risk behaviors. As the child develops, their curiosity and wishes to experiment are not always matched by their capacity to understand or respond to danger, and therefore, adult supervision is essential. For the caregiver (or designee), their ability takes into account their level of judgment, setting, degree of verbal and physical intervention, and how much time the caregiver actively spends supervising [61–65].

Minimizing exposure to infectious organisms in the home, childcare/daycare/school settings or recreational centers will help reduce risk. Supervisory rules include the type/number of visitors with associated restrictions as applicable, preventing exposure to children with childhood illnesses being brought into the home or child care setting. Ensuring sufficient supervision is provided by the handling of pets or animal-assisted interventions/therapy. There is strong evidence suggesting that animals pose a risk for pathogen spread via the oral-fecal or skin/fur routes [7,27,32,66].

Adherence to childhood immunization recommended schedules primarily against common vaccine-preventable infections can save lives through prevention and herd immunity [67]. Providing immunizations to children can heavily depend upon the child's age (could be too young to receive certain vaccines), their previous exposure to a certain disease(s) (with or without development of natural immunity), or parental attitude and/or beliefs that prohibit the administration of vaccines or other blood or blood products [7,27,28,68].

3. Conclusion

It is important and the right of all children of any age group to have a safe and infection-free environment. Effective strategies, when applied appropriately, can control and prevent infections in the pediatric population.

The literature review undertaken clearly supports the recommendation that IP&C programs need to be developed and tailored for specific pediatric age-groups. The factors that differ from adults need to be taken into consideration, including age, physical, and psycho-social factors that impact children's inability to follow IP&C standards; important role that the caregiver has in both prevention and transmission, and the need to address disease prevention strategies for those diseases that are known to occur most often among children, including those of an enteric and respiratory nature.

The authors identified areas that require further research and/or the need for more intensive study. These include studying the relationship between injuries or diseases that occur in the home or community and their impact on the healthcare settings; infection-related comparisons between different age groups; development of dedicated pediatric infection data-bases and guidelines, including the rates of CAUTI in NICUs; need to study the association and role of visitors in the transmission of infections within-the-healthcare setting as compared to the home environment; review of policies governing visitors within-the-healthcare setting; impact of viral shedding and need for resampling for clearance purposes, especially among the immunocompromised; and need for studies and guideline development on MDROs, especially ESBL and CRE, in relation to the pediatric population.

Ultimately, it is the caregiver's responsibility to oversee and ensure that safe care practices are being followed. This can be achieved by balancing and adhering to IP&C strategies within-the-healthcare and outside-of-the-healthcare setting. Each setting has the potential to influence and/or impact the other. As discussed in this paper, there is a comprehensive need for a proactive approach by all caregivers, oversight by an IP&C team, and strong support from management and other key stakeholders.

Conflicts of interest

The authors have no conflict of interest to report.

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