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ORIGINAL RESEARCH ARTICLE

Targeting zero catheter-related bloodstream infections in pediatric intensive care unit: a retrospective matched case-control study

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ABSTRACT

Introduction: The aim of this study was to evaluate the effectiveness and safety of a new three-component 'bundle' for insertion and management of centrally inserted central catheters (CICCs), designed to minimize catheter-related bloodstream infections (CRBSIs) in critically ill children.

Methods: Our 'bundle' has three components: insertion, management, and education. Insertion and management recommendations include: skin antisepsis with 2% chlorhexidine; maximal barrier precautions; ultrasound-guided venipuncture; tunneling of the catheter when a long indwelling time is expected; glue on the exit site; sutureless securement; use of transparent dressing; chlorhexidine sponge dressing on the 7th day; neutral displacement needle-free connectors. All CICCs were inserted by appropriately trained physicians proficient in a standardized simulation training program.

Results: We compared CRBSI rate per 1000 catheters-days of CICCs inserted before adoption of our new bundle with that of CICCs inserted after implementation of the bundle. CICCs inserted after adoption of the bundle remained in place for a mean of 2.2 days longer than those inserted before. We found a drop in CRBSI rate to 10%, from 15 per 1000 catheters-days to 1.5.

Conclusions: Our data suggest that a bundle aimed at minimizing CR-BSI in critically ill children should incorporate four practices: (1) ultrasound guidance, which minimizes contamination by reducing the number of attempts and possible break-down of aseptic technique; (2) tunneling the catheter to obtain exit site in the infra-clavicular area with reduced bacterial colonization; (3) glue, which seals and protects the exit site; (4) simulation-based education of the staff.

Keywords: Catheter-related bloodstream infections, Ultrasound-guided vascular access, Tunnelled catheters, Cyanoacrylate glue, Bundles, Catheter-related complications

Introduction

Background and rationale

Central venous catheters (CVCs) are common and indispensable in modern pediatric critical-care medicine for a variety of reasons. Common indications for CVC use are hemodynamic monitoring, repeated blood sampling, infusion of vasoactive medication, fluid replacement, antibiotic administration, hemodialysis, and parenteral nutrition. In addition to this, today more and more patients are discharged from the pediatric intensive care unit (PICU) to the ward requiring a medium-term or long-term CVC for the ongoing care. CVCs provide stable vascular access, but they are also associated with catheter-related bloodstream infection (CRBSI), which is still characterized by increased morbidity and attributable costs exceeding US$40,000 (1, 2). CRBSIs are multifactorial events with a reported incidence varying between 0.46 and 26.5 infections per 1000 catheter-days (3). Infection rates vary with catheter types, indications, insertion sites, dwell times and patients' underlying disease (3). Comprehensive interventions directed at CRBSI prevention including staff education and the use of insertion and maintenance bundles, have been associated with significant reductions in infection rates in critically ill children (4, 5). However, despite increasing

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research activity in CRBSI prevention and despite development and spread of the above-mentioned insertion and care bundles, the goal of zero infection for critically ill children is still not attainable.

Objective

This study was aimed to evaluate effectiveness, safety, feasibility and applicability of a new rigorously evidence-based insertion and care bundle adopted and implemented in our PICU and directed at targeting zero CRBSI in critically ill children.

Materials and methods

Study design and setting

This is a retrospective matched case-control study that was conducted in the 8-bed PICU of a large university hospital in Rome, Italy ("A. Gemelli" University Hospital, Catholic University of the Sacred Heart) after the approval of the Institutional Review Board (IRB) who waived the need for written informed consent. Our PICU is a tertiary referral center admitting 85 to 100 pediatric critically ill trauma patients per year.

Study population and catheter type

Our retrospective matched case-control study included all consecutive pediatric patients (aged >48 hours up to 16 years) who were admitted to our PICU from June 1, 2009 until June 30, 2014. Starting from January 1, 2012 in our institution we adopted and implemented a multicomponent evidence-based insertion and care bundle directed at targeting zero CRBSI and minimizing all other early and late complications (Tab. I). Sixty-four patients who had a new centrally inserted central venous catheter (CICC) placed according to our new insertion and care bundle during their intensive care unit (ICU) admission on or after January 1, 2012 and up to June 30, 2014 were included in the study group. Sixty-four patients who had a new CICC placed before the adoption of the new insertion and care bundle, starting from December 31, 2011 and going back to June 1, 2009, were included as controls.

We included tunneled CICCs in the study group according to our bundle and non-tunneled CICCs in the control group. Temporary dialysis catheters, "introducer" catheters and all catheters placed in emergency conditions were excluded. According to our bundle, in the study group we used 3F, 4F and 5F 2- or 3-lumen ProPICC CT Power Injectable as off-label multipurpose CICCs (MedComp, Inc, Harleysville, PA, USA). In the control group, short-term pediatric 4F and 5F triple-lumen or double-lumen catheters made by Vygon (Vygon, Inc., France) were used.

Catheter insertion technique and nursing care

All CICCs in both groups were inserted at bedside by appropriately trained physicians using ultrasound guidance (US-G). In particular, CICCs of the study group were inserted by expert physicians proficient in a standardized simulation-based training program (6, 7) aimed at obtaining a strict adherence to our new insertion and care bundle. Furthermore, all PICU nurses underwent a structured CICC care training and competency-based evaluation in order to perfectly adhere to maintenance practice provided by our bundle (7). All skills were taught along with evidence-based strategies for the prevention of CRBSI. According to our insertion and care bundle (Tab. I), the vein to be punctured was chosen after a structured clinically integrated ultrasound assessment of all possible options using the Rapid Central Vein Assessment (RaCeVA) protocol (8). US preliminary evaluation and US-G central venipuncture were performed with a Sonosite MicroMaxx ultrasound device equipped with a "Hockey Stick" linear probe (FUJIFILM SonoSite, Inc.). All CICCs in the control group were placed using a Seldinger technique, whereas all those in the study group were placed using a micro-introducer and a modified Seldinger technique. The insertion team chose the optimal vessel based on a goal vessel-to-catheter ratio of at least of 3:1, which is determined by pre-puncture US assessment. Policies adopted both in cases and in controls required preprocedural hand hygiene; use of maximum sterile technique including mask, cap, full gown, and gloves; head-to-toe patient draping; and skin antisepsis with 2% chlorhexidine solution, to dry before venipuncture. There was at least one assistant present, among whose tasks it was to observe for a possible breakdown of sterile technique. Disregarding the puncture site, in the study group, all CICCs were tunneled to move the exit site to the infraclavicular area. Correct catheter tip location was confirmed using the technique of intracavitary electrocardiography (EKG) or subcostal echocardiography, which allows direct or indirect visualization of the catheter's tip at the cavo-atrial junction. Following insertion, only in the study group, the exit site was sealed with cyanoacrylate glue allowing the first dressing change to be performed after 1 week. On the 7th day, a chlorhexidine-impregnated antimicrobial sponge was also placed at the exit site in the study group, whilst, in the control group it was placed since insertion. Each CICC was secured with a sutureless device and covered with a transparent dressing. Neutral displacement needle free connectors (NFC) and port protectors were used at the hubs. In our institution, all CICCs undergo daily visual assessments by nursing staff, and catheter dressings are changed approximately every 7 days using clean or sterile gloves. The entire medical team and the nursing staff perform daily assessments of ongoing needs for any kind of CVC including both CICCs and peripherally inserted central catheter (PICCs).

Data collection

Our PICU team maintains a prospective database that tracks demographic and outcome data for all admissions, which was queried to identify patients who had a new CICC during their admission to the PICU. All potential cases were manually reviewed to ensure that they met inclusion/exclusion criteria and to verify date and time of insertion and removal to ensure accuracy of CICC indwelling time. Patients were followed for CICC-related complications until the catheter was removed or the patient was

TABLE I - Insertion and maintenance bundle adopted in the group of cases

Insertion and maintenance bundle	Cases	Controls
1. Hand washing and maximal barrier precautions	Yes	Yes
2. Skin antisepsis with 2% chlorhexidine	Yes	Yes
3. Ultrasound pre-puncture evaluation through RaCeVA	Yes	No
4. Ultrasound guided venipuncture	Yes	Yes
5. Tunneling of the catheter so to obtain an exit site in the infraclavicular area	Yes	No
6. Sealing of the exit site with glue	Yes	No
7. Securement with sutureless device	Always	Inconsistently
8. Coverage with transparent semipermeable dressing	Yes	No
9. Chlorhexidine-impregnated sponges	After the 1st week	Since insertion
10. Use of neutral NFC and port protectors	Yes	Yes
11. Simulation-based standardized training program	Yes	No

RaCeVA = rapid central vein assessment; NFC = needle free connectors.

dismissed from the PICU. Data collectors were unaware of whether a subject was a case or a control and of the study hypothesis.

Outcomes

The primary endpoint was the rate per 1000 catheter-days of CR-BSI for CICCs placed after having adopted and implemented, through a simulation-based standardized training program, a new insertion and care bundle including (a) tunnelization, (b) sealing the exit site with glue, and (c) a structured global use of ultrasound, compared to the standard of care. All CICCs were followed until PICU discharge.

Secondary endpoints were the overall rate of symptomatic catheter-related deep venous thrombosis (CR-DVT), catheter occlusion, and accidental dislodgement.

Diagnosis

Catheter-related bloodstream infection (CRBSI) was defined using the standard Centers for Disease Control/National Healthcare Safety Network reporting definitions (9). According to Infectious Diseases Society of America (IDSA) guidelines, CRBSI events were diagnosed isolating the same organism from the catheter and the peripheral blood with a differential time to positivity of CICC-derived versus peripheral blood culture positivity of more than 2 hours (10, 11).

Statistics

For comparison of normally distributed, continuous data, we used a 2-sided Student's t-test. For continuous data that failed tests for normal distribution, we reported the median and used a non-parametric Wilcoxon rank sum test. For comparison of nominal data, we used a Pearson χ^2 test, or Fisher's exact test if the expected event rate was fewer than 5. A p value <0.05 was considered statistically significant. All data analyses were performed using SPSS statistical software (IBM, USA).

Results

We found a significantly higher severity of disease in the study group as reflected in the 24-hour Pediatric Index Mortality II (PIM II) score (p<0.001), invasive ventilator use, and length of PICU stay (Tab. II).

The veins punctured at different sites are specified in Table III, and the overall complications following catheter placement are outlined in Table IV.

We collected more than 1150 catheter-days of data, with 648 catheter-days in the study group and 503 catheter-days in the control group. The groups differed with respect to indwelling time, with catheters of the study group remaining in place for a mean of 2.2 days longer than those of the control group. We found a significant drop in CR-BSI rate from 15 per 1000 catheter-days in the control group to 1.5 per 1000 catheter-days in the study group (p<0.05) (Tab. IV).

TABLE II - Characteristics of the population studied

	Cases	Controls
Mean age (±SD), m	45.88 (±26.01)	78.01 (±50.0)
Female, %	31.7	47.9
Mean weight (±SD), kg	16.2 (±10.0)	26.63 (±18.03)
Median PICU LOS (IQR), d	12.0 (1.0-26.0)	5.0 (2.0-13.0)
Mean PIM II score (±SD)	8.29 (±2.70)	2.63 (±1.0)
Median ventilation duration (IQR), d	2.0 (.0-12.0)	1.0 (.0-5.5)
Organ dysfunction diagnosis (%)		
Cardiac, %	8.3	NR
Respiratory, %	16.7	NR
Neurological, %	35	NR
Oncologic, %	13.3	NR
Other, %	26.7	NR

SD = standard deviation; m = months; PICU LOS = pediatric intensive care unit length of stay; IQR = interquartile range; d = days; PIM II = Pediatric Index Mortality II score; NR = not reported.

TABLE III - Punctured veins at different sites

Veins	Cases	Controls
Right internal jugular vein at mid-neck, n (%)	0 (0%)	40 (62.5%)
Low lateral right internal jugular vein, n (%)	2 (3.12%)	11 (17.2%)
Left internal jugular vein at mid-neck, n (%)	0 (0%)	13 (20.3%)
Left brachiocephalic vein, n (%)	2 (3.12%)	0 (0%)
Right brachiocephalic vein, n (%)	52 (81.25%)	0 (0%)
Right axillary vein, n (%)	4 (6.25%)	0 (0%)
Left subclavian vein, n (%)	2 (3.12%)	0 (0%)
Right external jugular vein, n (%)	2 (3.12%)	0 (0%)

TABLE IV - Complication rates from insertion to PICU discharge

		Cases	Controls
Indwelling time (d)	Total	648	503
	Mean (±SD)	9.7 ± 3.1	7.5 ± 3.5
CR-BSI	No	1	8
	per 1000 catheter days	1.5	15
CR-DVT	No	0	1
Accidental dislodgements	No	0	3

CR-BSI = catheter-related bloodstream infections; CR-DVT = catheter-related deep vein thrombosis; PICU = pediatric intensive care unit; SD = standard deviation.

There were no episodes of symptomatic catheter-related thrombosis, no episodes of occlusion nor accidental dislodgements in the study group.

Furthermore, no cases of insertion-related pneumothorax or hemothorax were detected in any of the groups.

Discussion

CR-BSI still represents a relevant cause of morbidity and mortality in PICU (1, 2). It has been shown that CR-BSI is a multifactorial but preventable complication (12). We have demonstrated that an evidence-based insertion and care bundle aimed at reducing risk factors was associated with a significant decrease in CR-BSI rate (Tab. IV). Costello and coworkers, in a retrospective interventional study, showed a reduction in CR-BSI rate from 7.8/1,000 catheter-days to 2.3/1,000 catheter-days after a systematic intervention (5). In adult patients, Pronovost et al demonstrated that an evidence-based intervention resulted in an effective and sustained reduction in rates of CR-BSI (13).

Most recommendations of our bundle (hand washing and maximal barrier precautions; skin antisepsis with 2% chlorhexidine in; coverage with transparent semipermeable dressing and chlorhexidine-impregnated sponges; NFC disinfection; removal of nonessential catheters, etc.) are already well known to be effective in reducing infection risk. Four aspects make our bundle new and original:

1. Ultrasound guidance, which minimizes contamination by reducing the number of attempts and possible breakdown of aseptic technique.
2. Tunneling the catheter to obtain exit site in the infra-clavicular area with reduced bacterial colonization when a long indwelling catheter is expected (>7 days).
3. Glue, which seals and protects the exit site.
4. Education and assessment of procedural competence of the staff, which has been shown to have important implications for the quality of care.

Several guidelines also recommend the use of ultrasound to decrease the rate of CR-BSI in adults and children (14-18). Facilitating CICC placement by reducing the number of attempts and the risk of hematoma formation, ultrasound guidance may indirectly reduce the incidence of CRBSI and CR-DVT (14-19). In fact, the adoption of ultrasound guidance has been shown to have a significant favorable impact, both on the risk of catheter contamination and CRBSI and on the risk of CR-DVT (14).

Guidelines and some studies place emphasis on site selection (13-18). In fact, it is recommended to avoid femoral veins and use the subclavian vein, which is associated with lower risk of CR-BSI (13). Our findings suggest that the problem is not the vein but the exit site location of the catheter. CR-BSIs are related to the contamination risk at the exit site. We should take into account that different areas of the skin have different degrees of bacterial colonization. Furthermore, moisture, warmer areas of body, hair distribution, failure of dressing to adhere, are among relevant risk factors. On the other hand, various studies have demonstrated that when a long indwelling time is expected, tunneled catheters are preferred because of the lower risk of infection (20-22). When comparing the incidence of bloodstream infections of tunneled and totally implanted CICCs in children, most studies found a lower risk in the implanted group (20-22). Disregarding the puncture site, tunneling the catheter allows to move catheter's exit site onto the chest, a dry, flat and stable area with lower colonization, where dressing is optimal and the risk of infection is low. Moreover, by stopping bacteria spread along the catheter, the tunnel avoids their entrance into the vein. We used off-label Power Injectable PICCs, which are central catheters usually peripherally inserted, as a multipurpose CICC. The PICC is ideal for tunneling because it is longer than the traditional CICC and can be trimmed, easily tunneled and safely inserted into a central vein using a modified Seldinger technique via a microintroducer kit. Furthermore, the characteristic of power injectability has the additional advantage of tolerating high-pressure injection (up to 300-350 psi) of contrast media during radiological procedures and allows delivery of high flows of fluids for resuscitation.

Also sealing the exit site of catheters with cyanoacrylate glue reduces the risk of extraluminal contamination, presumably by reducing bacterial entrance through the skin breech (23). Furthermore, the glue reduces bleeding at the exit site and at the puncture site, and by stabilizing the catheter, reducing "in

and out" movement, the glue may decrease local damage to the endothelium and the risk of thrombosis (23, 24).

Sutures are no longer recommended and should be avoided since they cause disruption of the skin around the catheter exit site, causing inflammation and heavy colonization (15, 16). Guidelines recommend sutureless devices to stabilize the catheter (15-18). In the study group, the use of sutureless devices was systematic compared to the control group in which, instead, their use was inconsistent (14 cases out of 64) (Tab. I).

Our bundle was implemented after a simulation-based training program. All medical and nursing staffs were trained according to evidence-based recommendations of the World Congress on Vascular Access (WoCoVA) consensus conference (7, 25). Barsuk et al, in a single-center medical ICU, found that the rate of CRBSI, after a minimum proficiency simulation-based training model on standardized checklist, reduced from 3.2 per 1000 catheter-days to 0.5 per 1000 catheter-days (26). Simulation-based training on a checklist for insertion and care allowed us to maintain strict adherence to our bundle.

Limitations

Our study has several limitations. The first major limitation is its retrospective design. Furthermore, because it is a single-center study with a small number of collected catheter-days, we had a limited power to detect CR-BSI. Another limitation was our ability to identify only symptomatic catheter-related thrombosis.

Strengths

We studied pediatric admissions to our general medical/surgical PICU over a 5-year period, which makes our findings representative of a long period.

Conclusions

Our findings strongly support a multipurpose strategy, including the use of US-G, with specific preventive and educational measures and the promotion of good practices in order to reduce the incidence of CRBSI.

Despite progress in recent years that has significantly reduced CR-BSIs in ICU, the goal of zero infection is still not in range, not for adults, and even less so for children. We suggest that a bundle should incorporate three practices: US-G; tunneling the catheter when a long indwelling time is expected; sealing the exit site with cyanoacrylate glue. A simulation-based training program is essential and institutional efforts should be focused on promoting and implementing such educational protocols. Although we had a significant decrease in CR-BSI rate, it was not yet zero. To further decrease CR-BSIs, we could possibly develop an effective audit tool focused on catheter-care practices and refresher courses on optimal insertion procedures and maintenance care.

Further studies are needed to identify all potential risk factors of CR-BSI and to develop prevention strategies that can be incorporated in a multi-faceted bundle.

Disclosures

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Conflict of interest: None of the authors has financial interest related to this study to disclose.

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