

Original Communications

The Impact of Needleless Connector Device Design on Central Venous Catheter Occlusion in Children: A Prospective, Controlled Trial

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ABSTRACT. *Background:* Intraluminal occlusion is common in children with central venous catheters (CVCs). Although multiple factors predispose CVCs to occlusion, reflux of blood is frequently implicated. We hypothesized that use of either a single-valve or positive-pressure-valve needleless connector device would reduce CVC occlusion rates in comparison to a standard device. We further hypothesized that saline would be as effective as heparinized saline flush in preventing occlusion and infection. *Methods:* CVC lumens were prospectively capped with 1 of 3 needleless connector devices in a 4-group design. Group 1 lumens were capped with a standard device, group 2 with a single-valve device, group 3 with a positive-pressure-valve device flushed with heparinized saline, and group 4 with a positive-pressure-valve device flushed with saline. Data were obtained regarding occlusion

and infection rates and user satisfaction. *Results:* Three hundred sixty children with 599 CVC lumens completed the study. Complete occlusion occurred in 19/150 (12.7%) lumens in group 1 in comparison to 2/150 (1.3%) in group 2, 5/149 (3.4%) in group 3, and 6/150 (4%) in group 4 ($p < .05$). There was a trend toward a 2-fold greater infection rate in group 4. User satisfaction was higher in groups 2, 3, and 4 than group 1 ($p < .05$). *Conclusions:* CVCs capped with a single-valve or positive-pressure-valve needleless connector device have lower complete catheter occlusion rates than those capped with a standard device. Heparinized saline flush affords no advantages over saline in reducing occlusion rate; however, there was a trend toward lower infection rate with the use of heparinized saline. (*Journal of Parenteral and Enteral Nutrition* 30:85–90, 2006)

Central venous catheters have become essential in the management of adults and children with acute and chronic diseases. Though these devices are clearly beneficial, they are not without risks. One of the most frequent complications associated with the use of these devices is occlusion, which occurs in up to 25% of central venous catheters.^{1,2} Historical prospective data at Cincinnati Children's Hospital Medical Center (CCHMC) revealed a 12% catheter occlusion rate (internal data). Catheter occlusion can lead to restricted catheter use and delay or discontinuation of patient therapy, thus compromising the quality of care. In addition, the resulting inability to obtain blood samples through these malfunctioning devices can result in the need for peripheral venipuncture that is often difficult and traumatic in children. Characteristics that contribute to catheter occlusion include catheter composition, catheter size, various patient factors, infusate composition, local catheter use protocols, and the use of connector devices.^{3–5} A variety of needleless connector devices has been marketed, with claims that they can decrease central venous catheter occlusion and infection rates by preventing reflux of blood through the

catheter tip. Needleless connector devices are currently available with 4 basic designs: standard (no valve), single valve, dual valve, and positive pressure valve. Theoretically, needleless connector devices with an internal valve prevent retrograde movement of fluid and associated complications, including catheter occlusion and infection. A positive-pressure-valve needleless connector device was recently shown to be effective in significantly reducing total catheter occlusion rate in comparison to a standard connector device.^{6,7} There is, however, little additional published evidence supporting the use of one valve connector device design over another in the prevention of central venous catheter occlusion, infection, or other complications. We hypothesized that the use of either a single-valve or positive-pressure-valve needleless connector device would reduce central venous catheter occlusion rates in comparison to the use of a standard device in children with indwelling central venous catheters. In addition, we hypothesized that the use of saline-only flush would be as effective as heparinized saline flush in preventing occlusion and infection.

METHODS

Study Design

The CCHMC institutional review board approved the study and waived the requirement to obtain informed consent. The Central Venous Catheter Resource Team (CVCRT) at CCHMC is responsible for

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TABLE I
User satisfaction survey

Please rate the following questions on a scale of 1 to 5. A score of 1 indicates poor performance; a score of 5 indicates excellent performance.

Question

1. How many of these devices have you used?
 - a. 0–10
 - b. 11–49
 - c. 50–100
2. How satisfied were you with the effort required to attach device/system to central venous access device?
3. How satisfied were you with the time required to attach device/system to central access device?
4. How satisfied were you with the simplicity of device/system use?
5. How satisfied were you with syringe attachment and injection of fluids/medications?
6. How satisfied were you with the syringe attachment and removal of blood sample?
7. How satisfied were you with the IV infusion tubing attachment?

the oversight of all catheter-related issues for the institution. Using a prospective, sequential study design, all inpatients with newly placed nontunneled or tunneled central venous catheters in the Pediatric Intensive Care Unit (PICU), Cardiac Intensive Care Unit (CICU) and those patients referred to the CVCRT for peripherally inserted central catheter (PICC) placement were eligible for participation in the study. Four groups were studied. Group 1 consisted of central venous catheters capped with a standard needleless connector device (Interlink, Becton Dickinson and Company, Franklin Lakes, NJ), and a 10-unit/mL flush of heparinized saline was used. This device did not have any internal valve. Group 2 consisted of central venous catheters capped with a single-valve needleless connector device (Alaris Smartsite, Alaris Medical Systems, San Diego, CA) and flushed with 10 units/mL of heparinized saline. Group 3 consisted of central venous catheters capped with a positive-pressure-valve needleless connector device (BD Posi-Flow, Becton Dickinson) and flushed with 10 units/mL heparinized saline. In group 4, central venous catheters were capped with a positive-pressure-valve needleless connector device (BD Posi-Flow) and flushed with saline (0.9% sodium chloride). Each study phase was continued until at least 150 devices were studied in each group. Central venous catheters were placed according to standard CCHMC procedure. Once the catheter was successfully placed, the assigned needleless connector device was attached to the catheter hub using the standard CCHMC nursing procedure. A 3-minute scrub consisting of povidone-iodine (10% aqueous) followed by 70% isopropyl alcohol scrub was used for cleansing needleless connectors before IV system entry throughout the study. For lumens requiring continuous infusions, the needleless connector was placed after the continuous treatment was discontinued, and intermittent therapy was initiated. The needleless connector device was changed weekly or when indicated

per CCHMC protocol for the duration of the study. All therapies administered through each of the needleless connector devices were consistent with manufacturer's recommendations relating to dose, dilution, frequency, and rate. Only those devices in place for 3 or more consecutive days were included in the final data analysis. Before the beginning of each study phase, caregivers in each study location were extensively educated on the proper use of the respective needleless connector device. All caregivers had access to a CVCRT RN coinvestigator 24 hours each day for questions and problems. Patients exited the study for any of the following reasons: therapy was complete, the capped lumen was needed for continuous infusion, the needleless connector device was not consistently in place for 3 days, the catheter was removed, or the patient expired. At the end of each phase of the study, caregivers were asked to complete an anonymous user satisfaction survey (Table I) specific to that device.

Data Collection

Data collected included patient demographics; catheter type, size, length, and number of lumens; catheter duration; type of infusate; placement complications; and catheter complications that occurred throughout the course of therapy. Catheter complications included partial occlusion events (defined as the inability to aspirate but able to flush), complete occlusion (defined as the inability to aspirate or flush), mechanical complications (catheter malfunction, tears, breaks, needleless connector cracks, or other dysfunction), phlebitis, and catheter-related bloodstream infection (CRBSI). Decisions to obtain blood cultures were made by the primary care team according to the patient's clinical status. Positive blood or catheter-site cultures during the study were recorded. CRBSI was defined using standard Centers for Disease Control and Prevention definitions.^{8,9} Patient data were recorded on written case report forms.

Statistical Analysis

The primary outcome variable was the difference in the complete occlusion rate between each of the 4 groups. This outcome variable was used for sample size calculations. Assuming an 8% incidence of complete occlusion in group 1, a 4% incidence of complete occlusion in group 3, a 2-tailed α of .05, and a β of .2, it was determined that completed data from 140 needleless connector devices would be required in each group. Assuming a 7% dropout rate after enrollment, the investigators elected to enroll 150 devices per group. Secondary outcome variables included the difference in incidence of mechanical complications, device malfunction, infection rate, phlebitis, and user satisfaction between the 4 groups. Values are expressed as mean \pm SEM. Categorical variables were analyzed using χ^2 or Fisher's exact testing. Continuous variables were evaluated using the Student's *t*-test. A *p* value of $\leq .05$ was considered significant.

TABLE II
Baseline characteristics of patients and catheters within each study group

	Group 1 (n = 150)	Group 2 (n = 149)	Group 3 (n = 150)	Group 4 (n = 150)
Number of patients	98	90	85	87
Gender				
M	43	50	45	55
F	55	40	40	32
Mean age in months	44.0 ± 7.2	55.3 ± 7.7	36.1 ± 6.6	43.0 ± 6.5
Mean catheter size (Fr)	3.7 ± 0.1	4.2 ± 0.2	4.4 ± 0.1*	4.2 ± 0.2
Mean number of lumens	1.9 ± 0.1	1.9 ± 0.1	2.2 ± 0.1	2.1 ± 0.1
Mean days catheter duration	9.7 ± 0.7	8.2 ± 0.6*	7.3 ± 0.6†	7.4 ± 0.5*

**p* < .05 in comparison to group 1.
†*p* < .005 in comparison to group 1.

RESULTS

Overall, 392 children with 781 central venous catheter lumens were enrolled in the study. Thirty-two patients with 182 lumens met early exit criteria, resulting in 360 children with 599 central venous catheter lumens for final analysis. Catheters represented included nontunneled (76%), PICC (23%), and tunneled (1%). Mean patient age was 44.3 ± 3.5 months (53.6% male, 46.4% female). Mean catheter duration was 8.3 ± 0.3 days. Baseline characteristics in the 4 groups are noted in Table II. There were no significant differences detected between any of the study groups for gender and age. Patients in group 1 had a significantly smaller mean catheter size than patients in group 3. Mean catheter duration was significantly less in groups 2, 3, and 4 in comparison to group 1.

Table III displays the differences between the occlusion and complication rates between each group. The complete occlusion rates were significantly greater in group 1 (19/150, 12.7%) in comparison to group 2 (2/149, 1.3%), group 3 (5/150, 3.3%), and group 4 (6/150, 4%) (*p* < .05). In examining the occlusion rates per 1000 device days, there was a 2.1- to 7.4-fold reduction in complete occlusion rates in groups 2 through 4 in comparison to group 1. The complete occlusion rate was significantly lower in group 2 in comparison to group 1 (2.7 vs 20.1/1000 device-days, *p* = .003). There were no significant differences between the groups in

the incidence of partial occlusion, time to the first day of catheter occlusion, phlebitis, or mechanical complication rate or severity. There was a trend toward a greater CRBSI rate in the positive-pressure saline group, though this finding did not reach statistical significance.

The user satisfaction survey was administered to 132 nurses and was returned by 120 nurses, for an overall response rate of 90.9%. The results of these surveys are displayed in Figure 1. Scores for groups 3 and 4 were combined in analysis. Caregivers had experience with significantly more standard devices than either the valve or the positive-pressure-valve devices (*p* < .05). This finding is attributable to group 1 devices having been in use within the institution before the initiation of the study. There was significantly greater user satisfaction with the devices used in group 2, 3, and 4 in comparison to group 1's devices, as indicated by the responses to questions 3 through 7 (*p* < .05).

DISCUSSION

Central venous catheters play a vital role in the care of children with both chronic and acute diseases. Though essential for high-quality care, these devices are not without risk. One of the more common complications associated with central venous catheters is occlusion. Catheter occlusion has been associated with delays in therapy, interruption in monitoring, and the

TABLE III
Occlusion rates and other complications in each study group

	Group 1 (n = 150)	Group 2 (n = 149)	Group 3 (n = 150)	Group 4 (n = 150)
Complete occlusion	19 (12.7%)	2 (1.3%)‡	5 (3.3%)†	6 (4%)*
Partial occlusion	7 (4.7%)	11 (7.3%)	6 (4%)	6 (4%)
Total + partial occlusion	26 (17.3%)	13 (8.7%)	11 (7.3%)*	12 (8%)*
Complete occlusion rate (events/1000 device-days)	20.1	2.7†	8	9.3
Partial occlusion rate (events/1000 device-days)	7.4	15	9.6	9.3
Total + partial occlusion rate (events/1000 device-days)	27.6	17.7	17.6	18.7
Days to occlusion (range in days)	9.4 ± 1.5 (1–25)	6.1 ± 1.7 (4–8)	9.5 ± 1.4 (3–17)	7.1 ± 0.9 (1–11)
Catheter infection rate (BSI/1000 device-days)	5.3 (5 infections)	4.1 (3 infections)	4.8 (3 infections)	10.9 (7 infections)
Phlebitis	1	0	0	0
Mechanical complications	4 (2.7%)	7 (4.7%)	3 (2%)	3 (2%)

**p* < .05 in comparison to group 1.
†*p* < .01 in comparison to group 1.
‡*p* < .001 in comparison to group 1.
BSI, blood stream infection.

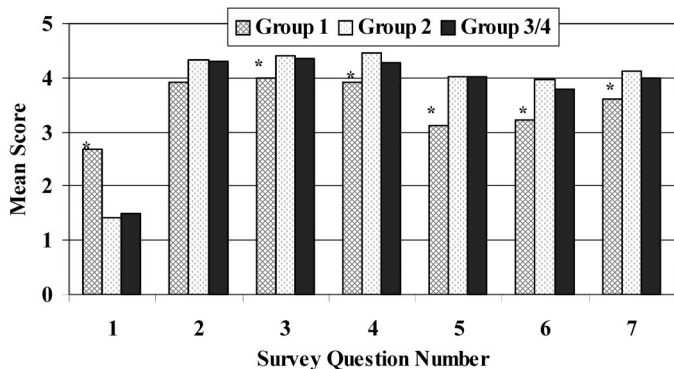


FIGURE 1. Results of the user satisfaction survey in all 4 study groups. Groups 3 and 4 were combined as the device was identical, with a different flush protocol. * $p < .05$.

need for treatments aimed at restoring patency.^{1,5,10} Unsuccessful attempts to restore catheter function often result in premature device removal.

There are many factors associated with central venous catheter occlusion. Peripherally placed catheter tips have significantly greater catheter occlusion complications than those that are centrally placed.¹¹ Mechanical problems are common and generally associated with a catheter tip that resides next to an intracardiac structure, against the wall of a blood vessel, or in a peripheral location.^{1,12,13} Catheters may also become obstructed secondary to accumulation of blood products.^{6,14} Though manufacturers do not generally recommend the use of small catheters for blood sampling, they are often used for this purpose.¹⁵ A recent study noted that blood sampling through 3-Fr PICC devices is effective, though with an increased rate of occlusion.¹⁵

There are several approaches effective in the prevention of catheter occlusion. In addition to avoiding inappropriate tip placement and blood sampling, routine flushing with heparin or saline,^{16–18} continuous infusion of maintenance fluids,¹⁹ continuous infusion of heparin-containing solutions,²⁰ and clamping of the catheter or the extension tubing after catheter flushing²¹ have also been described. In addition, selection of an appropriate needleless connector device may be an important factor in preventing catheter occlusion. Despite claims supporting the importance of needleless connector devices, the use of these caps in prevention of catheter occlusion is one of the least-studied preventive strategies. Reflux of blood into the catheter tip may play a significant role in catheter occlusion. The role of various needleless connector device designs on prevention of reflux is unclear.^{6,21,22} There are a number of needleless connector devices available, including standard (no valve), single-valve, dual-valve, and positive-pressure-valve designs. The contribution of each of these connector designs in preventing blood reflux and occlusion has not been well studied. A recent investigation by our group compared 161 positive-pressure-valve devices to 151 standard devices in 153 children with central venous catheters.⁶ This study revealed significantly less complete occlusions with the positive-

pressure-valve device than with the standard device (3.7% vs 11.9% respectively, $p = .012$). Positive-pressure-valve devices work by activating an antegrade flow of fluid through the catheter, thereby preventing reflux as the flush syringe is disconnected. There are few trials comparing single-valve or dual-valve devices to either standard or positive-pressure-valve devices.^{7,23} The primary purpose of our study was to broaden our understanding in needleless connector design and function by comparing the impact of standard, single-valve, and positive-pressure-valve needleless connector devices on central venous catheter occlusion rates.

Our results suggest a 3- to 9-fold lower complete occlusion rate in central venous catheters capped with either a single-valve or positive-pressure-valve device in comparison to a standard connector. These findings are very similar to a previous comparison between standard and positive-pressure-valve devices.⁶ We did not detect any significant difference between the complete occlusion rate in single- vs positive-pressure-valve devices. The complete occlusion protection afforded by valved connector devices is most likely secondary to the effect of these devices on minimizing accumulation of blood elements within the lumen of the catheter. Reflux of blood into the lumen after flushing was frequently noted when the standard device was used, despite a protocol to first flush, then clamp, and then disconnect the syringe. This same flush protocol was used with the single-valve needleless connector device. Clamping is likely the most important mechanism in eliminating blood reflux in both standard and single-valve devices. It is possible that flush-practice inconsistencies may have influenced the results within these 2 study arms. During the positive-pressure-valve device phase of the study, the flush protocol was changed to flush, disconnect, then clamp. This was necessary to allow the positive-pressure-valve device to activate, per manufacturer recommendations. This change in protocol was unlikely to have affected complete occlusion rates. Of note, the mean catheter size in group 1 subjects was smaller than group 3, and the mean catheter duration was greater in group 1 than all other groups. These 2 factors may have contributed to the differences in the primary outcome variable. However, when adjusted for catheter duration (events per 1000 device-days), the complete occlusion rate remained 2.1- to 7.4-fold lower in the single- and positive-pressure-valve device groups.

Despite the notable differences in complete occlusion rates, partial occlusion rates were not significantly different between any of the 3 device designs tested. Consistent with our previous findings,⁶ needleless cap design differences seem to afford little benefit in reducing the likely source of partial occlusions: blood-component accumulation on the external surface of the catheter.^{6,22}

There is a paucity of data available comparing infection rates between different needleless connector designs. Casey et al²⁴ recently demonstrated a reduced microbial contamination rate in positive-pressure-valve connectors compared to standard connectors. Though our data did not suggest any statistically sig-

nificant differences between the groups, there was a notable 2-fold greater CRBSI rate in group 4 subjects vs those enrolled in the other groups. We estimate that 600 devices would need to be studied in each group for this difference to be adequately powered to detect a statistically significant difference with $\alpha = .05$ and $\beta = .7$. The connector devices in group 4 were flushed with saline only, whereas devices in groups 1–3 were flushed with heparinized saline. The increased infection rate in the positive-pressure-device group flushed with saline in the current study was similar to the increased rate found in the positive-pressure-device group flushed with saline in our previous study.⁶ Heparin flush solutions contain preservatives with antimicrobial activity, which may have explained the differences in infection rates.²⁵ In addition, prophylactic heparin has been noted to reduce the risk of catheter-related thrombosis, a factor associated with CRBSI.²⁶ The use of heparin-containing flush solutions may play an important role in protection against catheter bacterial growth, and this subject will require further investigation.

Several factors are important in decisions to adopt new device technology into a health care organization, such as device safety, usability, reliability, cost, and user satisfaction. Clinician satisfaction was significantly higher with the use of both the single-valve and positive-pressure-valve devices compared to the standard device. Users rated the 2-valved connector devices higher in many areas, including the time required to attach the device, the simplicity of the device, syringe attachment and injection of fluids/medications, syringe attachment and removal of blood, and in attachment of IV infusion tubing. The results of the user satisfaction survey, when combined with complete occlusion rates and cost data, were instrumental in adopting the single-valve connector device at CCHMC. However, after this change was implemented across the institution, numerous user complaints were reported regarding the single-valve device. The most significant comments were related to retrograde blood return into the catheter and the external chamber of the connector which occurred after the procedural flush protocol. Because of these concerns, a follow-up user satisfaction survey was distributed to 243 individuals and returned by 195 (80.2% response rate). This new survey contained an additional statement: "I am satisfied with this product and find it easy to use and problem free." In response to this question, 46/195 (23.6%) strongly agreed, 77/195 (39.5%) agreed, 46/195 (23.6%) were neutral, 22/195 (11.3%) disagreed, and 4/195 (2%) strongly disagreed. The most commonly reported problems were (1) retrograde blood return into the catheter or needleless connector, (2) frequent need to change the connector device because of blood stasis in the device chamber, and (3) the need to flush catheters more frequently than standard protocol. These data indicated new concerns over the frequency of cap failure not detected in the original study survey and pointed out the need for continued monitoring of outcomes data subsequent to implementation of a new device.

CONCLUSIONS

In conclusion, single-valve and positive-pressure-valve needleless connector devices are effective in reducing complete occlusion rates in children with central venous catheters when compared with standard connector devices. The additional cost of these devices appears to be warranted in avoiding the difficulties associated with catheter malfunction, delays in care, and treatment costs.²⁷ Blood reflux in central venous catheter lumens capped with the single-valve device used in this study remains to be an ongoing concern. The contribution of this problem to replacement of single-valve devices, infection rates, and cost requires further study before this device design can be recommended. Saline flush protocols may be associated with a greater infection rate than heparinized saline flush protocols, and further study is also required.

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