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Am J Kidney Dis. Author manuscript; available in PMC 2022 June 14.

Published in final edited form as:

Am J Kidney Dis. 2020 July ; 76(1): 82–89. doi:10.1053/j.ajkd.2019.11.006.

Risk of Vascular Access Infection Associated With Buttonhole Cannulation of Fistulas: Data From the National Healthcare Safety Network

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Abstract

Rationale & Objective: Compared with conventional (rope-ladder cannulation [RLC]) methods, use of buttonhole cannulation (BHC) to access arteriovenous fistulas (AVFs) may be associated with increased risk for bloodstream infection and other vascular access–related infection. We used national surveillance data to evaluate the infection burden and risk among in-center hemodialysis patients with AVFs using BHC.

Study Design: Descriptive analysis of infections and related events and retrospective observational cohort study using National Healthcare Safety Network (NHSN) surveillance data.

Setting & Participants: US patients receiving hemodialysis treated in outpatient dialysis centers.

Predictors: AVF cannulation methods, dialysis facility characteristics, and infection control practices.

Outcomes: Access-related bloodstream infection; local access-site infection; intravenous (IV) antimicrobial start.

Analytic Approach: Description of frequency and rate of infections; adjusted relative risk (aRR) for infection with BHC versus RLC estimated using Poisson regression.

Results: During 2013 to 2014, there were 2,466 access-related bloodstream infections, 3,169 local access-site infections, and 13,726 IV antimicrobial starts among patients accessed using BHC. *Staphylococcus aureus* was the most common pathogen, present in half (52%) of the BHC access–related bloodstream infections. Hospitalization was frequent among BHC access–related

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Authors' Contributions: Research idea and study design: ML, PRP, DN, HG; data acquisition: PRP, DN, AS, CL; data analysis/interpretation: ML, PRP, DN, HG; supervision and mentorship: PRP, DN. Each author contributed important intellectual content during manuscript drafting or revision and accepts accountability for the overall work by ensuring that questions pertaining to the accuracy or integrity of any portion of the work are appropriately investigated and resolved.

Financial Disclosure: The authors declare that they have no relevant financial interests.

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bloodstream infections (37%). In 2014, 9% (n = 271,980) of all AVF patient-months reported to NHSN were associated with BHC. After adjusting for facility characteristics and practices, BHC was associated with significantly higher risk for access-related bloodstream infection (aRR, 2.6; 95% CI, 2.4–2.8) and local access-site infection (aRR, 1.5; 95% CI, 1.4–1.6) than RLC, but was not associated with increased risk for IV antimicrobial start.

Limitations: Data for facility practices were self-reported and not patient specific.

Conclusions: BHC was associated with higher risk for vascular access–related infection than RLC among in-center hemodialysis patients. Decisions regarding the use of BHC in dialysis centers should take into account the higher risk for infection. Studies are needed to evaluate infection control measures that may reduce infections related to BHC.

Arteriovenous fistulas (AVFs) are the preferred vascular access type for hemodialysis (HD) due to the low rate of complications, including infection, and prolonged patency compared with other vascular access types.[1–3] Buttonhole cannulation (BHC), or "constant site" cannulation, is a technique in which cannulation occurs with blunt needles using an established track created by repeatedly cannulating at the same site, angle, and depth so that scar tissue forms a tunnel.[4] This method differs from the conventional rope-ladder method in which cannulation sites are distributed along the entire length of the AVF. The BHC technique was initially used for individuals with limited space for cannulation because of a short AVF or large aneurysms[5,6] but has since been applied more broadly to patients with AVFs.

Patients who receive HD are at high risk for infections because they have impaired immune defenses and require frequent access to the bloodstream.[7–9] Some studies have suggested that BHC increases this risk for both bloodstream and local access-site infections,[10–18] but these studies included few dialysis centers, were restricted to home HD patients, or focused on infections due to a specific pathogen. This has made it difficult to pool results or generalize the conclusions of these studies to a larger population. Data for dialysis-associated infections and other related events are reported by more than 6,000 US outpatient HD facilities to the National Healthcare Safety Network (NHSN), a surveillance system for health care–associated infections. To determine the risk for vascular access–related infection associated with BHC among in-center HD patients in US dialysis clinics, we used data from NHSN to evaluate the infection burden and risk attributed to BHC.

Methods

NHSN Dialysis Event Surveillance

NHSN is a system for tracking health care–associated infections and related events operated by the US Centers for Disease Control and Prevention (CDC).[19] Surveillance of outpatient HD events is conducted through the Dialysis Event Surveillance module in NHSN.[20] Freestanding and hospital-based outpatient dialysis clinics that provide in-center HD are eligible to report events among their patients to this module in NHSN.[21] Dialysis events such as access-related bloodstream infection, local access-site infection, and intravenous (IV) antimicrobial start are reported using a standard data collection form. The data collected for these events include information about patient demographics, all vascular

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access types that the patient had at the time of the event, AVF patients' primary method of cannulation, clinical symptoms associated with the event (eg, fever, chills, and hypotension), pathogens isolated from blood, and select outcomes (ie, hospitalization and death).[22] Multiple events can occur and be reported concurrently. For each month, centers confirm compliance with the reporting protocol and confirm accuracy when zero events were reported.

Ethical Review

These data were collected as a part of public health surveillance and are not considered to fall within the definition of research as specified in 45 CFR 46.102(l). As a result, this analysis was not submitted for human subjects research determination.

NHSN Definitions

An access-related bloodstream infection is defined by the following criteria: (1) a positive blood culture from a specimen collected in the outpatient setting or within 1 calendar day after a hospital admission (ie, on the day of or day after admission to the hospital), (2) the patient had no positive blood culture reported in the preceding 21 days, and (3) the suspected source is reported as the vascular access or uncertain. For each access-related bloodstream infection, between 1 and 3 pathogens isolated from the blood may be reported, along with select antimicrobial susceptibilities of each pathogen. Susceptibility to antibiotics is reported as susceptible, intermediate, resistant, or not tested.[23]

A local access-site infection is pus, redness, or increased swelling of the vascular access site reported in the absence of an access-related bloodstream infection. An access-related bloodstream infection with pus, redness, or swelling at a vascular access site is considered to be only an access-related bloodstream infection, not a local access-site infection. There must be at least 21 days separating the onset of signs and symptoms of infection at the vascular access site in the same patient for the second episode to be reported.

An IV antimicrobial start is any outpatient initiation of IV antibiotic or antifungal medication therapy in a patient who has not received such medications in the previous 21 days. IV antimicrobial starts can be continuations of inpatient antimicrobial treatment (ie, new to the outpatient facility). Complete NHSN Dialysis Event surveillance data collection and reporting methods are publicly available (https://www.cdc.gov/nhsn/dialysis/event/index.html).

Denominator Reporting

Each month, outpatient dialysis centers report denominator data as the number of patients who received outpatient HD in the center on the first 2 working days of the month, classified by patients' vascular access type using a standardized form.[24] If a patient has multiple vascular accesses, only the vascular access type with the highest risk for infection is counted, using the following risk scale: non-tunneled central venous catheter (CVC) greater than tunneled CVC greater than other access devices (eg, catheter-graft hybrid device) greater than arteriovenous graft greater than AVF. Patients in the census count who were

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reported under AVF as the highest risk access type are further subcategorized based on whether BHC was their primary method of cannulation.

Outpatient Dialysis Center Practices Survey

Each dialysis center participating in NHSN completes an annual survey about facility characteristics (eg, ownership, hospital affiliation, and number of stations), BHC questions (eg, approximate volume of AVF patients receiving BHC and the person who most often performs it), and infection control practices and procedures, which includes practices related to AVF precannulation site cleansing and site preparation.[25]

BHC Data Collection and Classification

In 2012, NHSN introduced a new set of numerator and denominator data collection fields for the method of AVF cannulation. Numerator (events) and denominator (patient-months) data were categorized by whether a patient's fistula was primarily accessed using BHC technique (BHC patients) or another technique. However, denominator data for BHC were not completely captured until 2014. All patients with AVFs without BHC as the primary method of cannulation were assumed to have used the rope-ladder cannulation (RLC) method. Data from the 2014 annual survey (or most recent available survey before 2015) about facility characteristics and infection control practices were merged with aggregated Dialysis Event data by facility.

Statistical Analysis

We summarized events in BHC patients and compared rates of access-related bloodstream infections, local access-site infections, and IV antimicrobial starts among BHC patients with those among RLC patients. Access-related bloodstream infection was evaluated as the primary outcome, while local access-site infection and IV antimicrobial start were evaluated as secondary outcomes. Data cleaning resulted in the exclusion of a small number of events (0.1% of all events reported). For example, duplicate events that should have been prevented by business rules in the NHSN application were removed.

We determined the frequency of access-related bloodstream infections, local access-site infections, and IV antimicrobial starts by pooling the number of these events in BHC patients during 2013 and 2014, including events in patients who had additional vascular access types other than AVFs. We summarized and compared the frequency of patient demographics, vascular access types present, time from AVF placement to event, clinical symptoms, and associated outcomes for access-related bloodstream infections occurring during 2013 to 2014 between BHC events and RLC events. We also identified the most common pathogens for access-related bloodstream infections and compared the pathogen frequency of BHC events and RLC events. Because up to 3 pathogens can be reported per bloodstream infection, the total number of pathogens could be greater than the number of infections. NHSN does not collect pathogen information from laboratory culture results for local access-site infection or IV antimicrobial start event types.

To test the hypothesis that BHC is associated with higher rates of vascular access infections and related events, rates of access-related bloodstream infections, local access-site

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infections, and IV antimicrobial starts were compared between BHC and RLC. Pathogen frequency for access-related bloodstream infections was also compared between BHC and RLC. For the event rate comparisons, only data reported for 2014 were used because of missing BHC denominator data before 2014. Further, we excluded events in patients whose highest risk vascular access was not an AVF because this access could potentially be responsible for the infection events. Event data associated with monthly denominators that were missing or denominator data that had a corresponding unconfirmed zero numerator were also excluded. Among facilities for which data were included in the analysis, we described the frequency of facility characteristics and relevant practices using data from the annual survey. We compared rates of events by cannulation method using a Poisson model to estimate crude relative risk (RR) and RR adjusted for facility practices. Log of patient-months was used as an offset term in the Poisson regression and RR was adjusted for facility characteristics and infection prevention practices with a clinically plausible relationship and statistically significant association (based on $P < 0.05$) with infections after assessing variables for collinearity (Box 1). All data were analyzed using SAS, version 9.4 (SAS Institute).

Results

BHC Event Descriptive Analysis

A total of 2,466 access-related bloodstream infections, 3,169 local access-site infections, and 13,726 IV antimicrobial starts occurred in 2013 to 2014 among BHC patients in 6,088 facilities. Among BHC access-related bloodstream infections, hospitalization as a result of the event was common (37%) and the median time from AVF placement to access-related bloodstream infection was approximately 3 years (Table 1).

Clinical and pathogen information for access-related bloodstream infections associated with BHC and RLC can be found in Table 1. Fever was the most common systemic symptom for access-related bloodstream infections associated with both BHC and RLC. Chills or rigors were the second most common symptom. Pus, redness, or increased swelling at the fistula site was significantly more common among BHC access–related bloodstream infections compared with RLC access–related bloodstream infections (31% vs 11%; $P < 0.001$). *Staphylococcus aureus* was the most common pathogen for both BHC and RLC access–related bloodstream infections regardless of cannulation method, followed by *Staphylococcus epidermidis* and coagulase-negative staphylococcus not otherwise specified. *S aureus* was significantly more common among BHC access–related bloodstream infections compared with RLC access–related bloodstream infections ($P < 0.001$). The percentage of *S aureus* access-related bloodstream infections that were methicillin-resistant *S aureus* was 22% for BHC and 31% for RLC ($P < 0.001$). The frequency of hospitalization was slightly higher for RLC access–related bloodstream infections (41%) compared with BHC access–related bloodstream infections (37%; $P < 0.001$).

Prevalence of BHC

Of the 2,874,203 AVF patient-months reported to NHSN in 2014, a total of 9% (271,980 patient-months) were associated with BHC; the rest were associated with RLC. Of the 6,010

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facilities included in this analysis, 4,239 (71%) facilities had at least 1 in-center patient undergoing BHC during 2014.

Facility Characteristics and BHC Practices

Table 2 shows the frequency of facility characteristics and practices among facilities for which data were included in the analysis. The majority of facilities were for profit (86%) and affiliated with a chain of dialysis facilities (90%). Few were affiliated with a hospital (10%) or provided home HD services (18%). Based on general AVF care practices reported by facilities, washing with soap and water (75%) was the most common AVF cleansing method, while alcohol (49%) was the most common agent used for AVF site preparation. Although 4,239 facilities submitted monthly data reports demonstrating at least 1 in-center patient undergoing BHC during 2014, there were 3,281 facilities that reported having any fistula patients using BHC at the time they completed the annual survey (typically at the start of the year). In these 3,281 facilities that reported performing BHC, use of antimicrobial ointment at the BHC site to prevent infections was relatively uncommon (11%) and technicians (75%) were the most common persons to perform BHC.

Event Rate Analysis

Table 3 shows the numerator event count data, denominator patient-month data, pooled mean rates, and RR (crude and adjusted [aRR] for facility characteristics). For the 6,010 facilities for which data were included, BHC was associated with a higher crude risk for access-related bloodstream infection (RR, 3.3), local access-site infection (RR, 1.9), and IV antimicrobial start (RR, 1.2). When adjusted for facility characteristics and self-reported infection control practices, the increased risk associated with BHC remained for access-related bloodstream infection (aRR, 2.6; 95% confidence interval [CI], 2.4–2.8) and local access-site infection (aRR, 1.5; 95% CI, 1.4–1.6), but did not reach statistical significance for IV antimicrobial start (aRR, 1.1; 95% CI, 1.0–1.1). The results in Table 3 accounted for factors such as large dialysis organization membership and having a greater proportion of AVF patients receiving BHC, which are facility characteristics that were associated with risk for access-related bloodstream infections (Table S1).

Discussion

In this analysis of in-center HD patient data reported by several thousand facilities, we found that BHC was associated with higher rates and increased risk for access-related bloodstream infection and local access-site infection, even when accounting for select facility characteristics and practices. Of the 428,000 patients who undergo maintenance HD in the United States, ~63% use an AVF.[26] The high risk for vascular access infection and other complications among patients with a CVC has been well established[3,6,20] and AVFs are generally considered the safest HD vascular access type. Vascular access infections in AVF patients are an important issue because they can affect a large population of HD patients and can result in outcomes including hospitalization, sepsis, and related complications. During a 2-year period, a total of 5,635 vascular access infections among BHC patients were reported to NHSN (2,466 BHC access–related bloodstream infections and 3,169 BHC local access-site infections).

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Based on our analysis of patient census information reported to NHSN, BHC is a practice that involves many patients undergoing dialysis and the facilities that care for them. Almost one-tenth of the US in-center HD population with AVFs underwent cannulation using the buttonhole technique in 2014. Furthermore, of the 6,010 facilities included in this analysis, close to 71% had at least 1 BHC patient on census during 2014. By contrast, a study that examined AVF cannulation methods among European countries, South Africa, and Turkey in 2009 estimated that BHC was used for 6% of patients surveyed and in 13% of centers.[27,28]

Prior evidence on the overall benefits and risks of BHC has been mixed. Early research suggested that BHC may be associated with reduced pain,[4,13,29,30] improved ease of cannulation,[31,32] decreased access-related complications such as hematoma or aneurysm,[10,13,17,32,33] decreased need for access interventions,[32,33] and longer vascular access survival.[27,33] BHC also allows patients to self-cannulate, which may increase patient empowerment and facilitate home HD. Because skin integrity is disrupted and scab removal requires additional infection control efforts, risk for infections is a concern with BHC. Bacteria can colonize the BHC track,[34] just as they colonize the skin, and may cause infections when complete antisepsis is not achieved and scab removal is not properly performed.

Although existing evidence on the overall benefits and risks of BHC is mixed, our findings support numerous other studies suggesting higher risk for infection among patients undergoing BHC and contribute evidence to assist clinicians and patients m their decision making.[4,5,10,12–17,29–33,35–37] In this analysis, BHC was associated with 2.6 times greater risk for access-related bloodstream infection and 1.5 times greater risk for local access-site infection compared with RLC after adjusting for various facility-level factors. Considering BHC as an intervention, we estimated that the number needed to harm was 370 for access-related bloodstream infection and 417 for local access-site infection. The pooled mean rate of BHC access–related bloodstream infections (0.39/100 patient-months) was higher than RLC access–related bloodstream infections (0.12/100 patient-months), but substantially lower than that reported in the literature among patients with CVCs (1.83/100 patient-months).[20] BHC was not significantly associated with increased risk for IV antimicrobial starts. It is possible that vascular access infections are a relatively minor contributor to all antibiotic starts in AVF patients.

BHC access–related bloodstream infections were more likely to be accompanied by signs of infection (pus, redness, and increased swelling) at the fistula site, highlighting the importance of infection prevention and control practices related to fistula care. *S aureus* was the most common pathogen reported among BHC access–related bloodstream infections, responsible for half of these events and significantly more common compared with RLC access–related bloodstream infections. This might be explained by studies that have found that *S aureus* and other *Staphylococcus* species colonized the buttonhole track even after the entry site was disinfected.[34,38] The 3 most common organisms are considered skin microbiota, which is consistent with the report by Nesrallah et al[11] and suggests that the ability to achieve proper skin and track asepsis may play a role in these infections. Topical antimicrobial ointment has been studied to reduce infections related to BHC[11]; decolonization strategies might also warrant broader consideration.

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This study has several strengths and limitations. Our results are strengthened by the use of robust nationwide surveillance data collected from more than 6,000 US dialysis facilities, using a standardized protocol and data collection forms. In addition to determining whether there was a higher rate of infection associated with BHC, the analysis was able to account for facility factors and quantify risk.

Study limitations include the use of surveillance definitions for dialysis event types, which may not have included all important diagnostic or clinical criteria. The information collected for each event was not comprehensive and did not include details such as duration of buttonhole use before the event or reason for BHC use, and we did not collect information on the expertise and infection control practices of individual cannulators. Data for patient characteristics could not be included in the multivariable model or risk analysis because they were not available for patients who did not experience an access-related bloodstream infection or other reported event. Although we attempted to adjust for facility practices, our analysis was not designed to evaluate associations between specific infection prevention practices and infection risk. The facility practices included in the analysis were self-reported and might not reflect the quality or consistency with which practices were performed. Last, we did not evaluate the risk of BHC in home settings.

We found that BHC performed on in-center HD patients was associated with increased risk for vascular access infection events, even when accounting for facility characteristics and practices. We believe that these findings support other published studies, which collectively suggest that clinicians and patients should take into account the increased risk for infection associated with BHC when deciding on cannulation method. Use of BHC in dialysis centers should potentially be limited and restricted to circumstances for which benefits of BHC outweigh the infection risk. Data from NHSN suggest that BHC is already becoming less common in HD centers, with the proportion of patient-months associated with BHC declining since 2014, but there remains a large burden of BHC use with almost 80,000 patient-months associated with BHC in 2016. Additional studies may be needed to evaluate the impact of infection prevention and control interventions on infections associated with BHC, including techniques for skin antisepsis, decolonization, and scab removal.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Support:

This work was funded by the CDC, which was involved in study design, data collection, analysis, reporting, and submission for publication.

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Box 1.

Description of Dialysis Facility Characteristics and Infection Control Practices From the 2014 NHSN Survey Accounted for in the Model for Adjusted Relative Risk

- Facility ownership (for profit vs not for profit)
- Membership in a group or chain of dialysis facilities
- Number of dialysis stations
- Use of recommended antiseptics for AVF site preparation precannulation
- Provision of home hemodialysis services
- Membership in a large dialysis organization
- Hospital affiliation
- Percent of facility AVF patients using BHC
- Prophylactic use of antimicrobial ointment at BHC site
- Person performing BHC

Abbreviations: AVF, arteriovenous fistula; BHC, buttonhole

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Table 1.

Comparison of Characteristics of ARBSIs by AVF Cannulation Method, NHSN 2013–2014

	ARBSIs		
	BHC (n = 2,466)	**RLC (n = 13,600)**	***P*** [a]
Patient age, y	57 [47–67]	59 [49–70]	<0.001
No. of mo between access placement and event[b]	36.9 [21.2–58.0]	5.7 [2.6–21.2]	<0.001
Male sex	1,612 (65%)	8,273 (61%)	<0.001
Pus, redness, swelling at AVF site	772 (31%)	1,558 (11%)	<0.001
Other symptoms/problems			
Fever	1,265 (51%)	6,543 (48%)	0.004
Chills or rigors	932 (38%)	5,843 (43%)	<0.001
Cellulitis	131 (5%)	344 (3%)	<0.001
Wound (not related to AVF access) with pus or increased redness	26 (1%)	112 (1%)	0.3
Pneumonia/respiratory infection	41 (2%)	122 (1%)	0.001
Hypotension	61 (2%)	304 (2%)	0.5
None of these symptoms/problems	870 (35%)	4,781 (35%)	0.9
Outcomes			
Hospitalization	915 (37%)	5,577 (41%)	<0.001
Death	39 (2%)	166 (1%)	0.1
Pathogens			
Staphylococcus aureus	1,282 (52%)	4,403 (32%)	<0.001
Staphylococcus epidermidis	232 (9%)	2,898 (21%)	<0.001
Coagulase-negative staphylococcus NOS	221 (9%)	1,057 (8%)	0.04
Staphylococcus lugdunensis	193 (8%)	415 (3%)	<0.001
Enterococcus faecalis	94 (4%)	627 (5%)	0.08
Gram-positive cocci, unspecified	75 (3%)	262 (2%)	<0.001
Escherichia coli	54 (2%)	520 (4%)	<0.001
Enterobacter cloacae	22 (1%)	451 (3%)	<0.001
Klebsiella pneumoniae	22 (1%)	330 (2%)	<0.001
Pseudomonas aeruginosa	12 (<1%)	271 (2%)	<0.001

Note: Values for continuous variables given as median [interquartile range]; for categorical variables, as count (percentage).

Abbreviations: ARBSI, access-related bloodstream infection; AVF, arteriovenous fistula; BHC, button hole cannulation; NHSN, National Healthcare Safety Network; NOS, not otherwise specified; RLC, rope-ladder cannulation.

[a] χ^2 test for categorical variables or Wilcoxon rank sum test for continuous variables.

[b] Calculated among 11,746 ARBSIs (1,689 BHC and 10,057 RLC) for which this variable was reported.

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Table 2.

Facility Characteristics and BHC Practices Based on Survey Data, NHSN 2014

Parameter	Value
Facility Characteristics (n= 6,010)	
Facility ownership	
For profit	5,147 (86%)
Governmental not for profit	50 (1%)
Nongovernmental not for profit	813 (13%)
Affiliated with group or chain of dialysis facilities	5,404 (90%)
Affiliated with a large dialysis organization	3,795 (63%)
Hospital affiliated	572 (10%)
Types of patients receiving BHC (n = 3,756)	
In-center HD patients only	3,085 (82%)
Home HD patients only	87 (2%)
Both home and in-center HD patients	584 (16%)
Frequency of patients undergoing BHC (n = 5,125)[a]	
All	27 (<1%)
Most	189 (4%)
Some	3,065 (60%)
None	1,844 (36%)
No. of dialysis stations[b]	17 [1–96]
Facility AVF Care Practices (n= 6,010)	
AVF site cleansing method	
Alcohol	799 (13%)
Chlorhexidine	73 (1%)
Alcohol and chlorhexidine	206 (4%)
Soap	4,502 (75%)
Other	131 (2%)
None	139 (2%)
Missing	160 (3%)
AVF preparation method	
Alcohol	2,937 (49%)
Chlorhexidine	818 (13%)
Alcohol and chlorhexidine	66 (1%)
Povidone-iodine	1,260 (21%)
Sodium hypochlorite	761 (13%)
Other	6 (<1%)
Nothing	2 (<1%)
Missing	160 (3%)

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Parameter	Value
Facility BHC Practices[c] (n= 3,281)	
Types of patients receiving BHC[c]	
In-center HD patients only	2,686 (82%)
Home HD patients only	71 (2%)
Both home and in-center HD patients	523 (16%)
Missing	1 (<1%)
Routine use of antimicrobial ointment at BHC site to prevent infections[c]	
Yes	370 (11%)
No	2,910 (89%)
Missing	1 (<1%)
Person most often performing BHC[c]	
Nurse	499 (15%)
Technician	2,452 (75%)
Patient	154 (5%)
Other	104 (3%)
Missing	72 (2%)

Abbreviations: AVF, arteriovenous fistula; BHC, buttonhole cannulation; HD, hemodialysis; NHSN, National Healthcare Safety Network.

[a]Among 5,125 facilities with responses; 885 facilities with missing response were not included.

[b]Given as median [range].

[c]Among 3,281 facilities reporting on the annual survey that the frequency of patients undergoing BHC was all, most, or some. Facilities reporting the frequency as none or missing were not included.

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Table 3.

Number and Rates of Events Associated With BHC and RLC, NHSN 2014

	BHC			RLC			RR (95% CI)	
	No. of Events	Patient-mo	Pooled Mean Rate (per 100 patient-mo)	No. of Events	Patient-mo	Pooled Mean Rate (per 100 patient-mo)	Crude	Adjusted[a]
Access-related bloodstream infection	1,068	271,891	0.39	3,032	2,600,852	0.12	3.3 (3.1–3.6)	2.6 (2.4–2.8)
Local access-site infection	1,327	271,883	0.49	6,536	2,600,780	0.25	1.9 (1.8–2.0)	1.5 (1.4–1.6)
IV antimicrobial start	5,921	271,901	2.18	46,112	2,600,908	1.77	1.2 (1.2–1.3)	1.1 (1.0–1.1)

Abbreviations: AVF, arteriovenous fistula; BHC, buttonhole cannulation; CI, confidence interval; IV, intravenous; NHSN, National Healthcare Safety Network; RLC, rope-ladder cannulation; RR, relative risk.

[a]Adjusted for facility ownership (profit vs not for profit), part of a dialysis group/chain, part of a large dialysis organization, hospital affiliation, home hemodialysis services provided, number of dialysis stations, percent of AVF patients receiving BHC, AVF site cleansing method, AVF site preparation method, prophylactic use of antimicrobial ointment at BHC site, and category of staff member performing BHC.

Am J Kidney Dis. Author manuscript; available in PMC 2022 June 14.