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Development of a Protocol for Testing the Effectiveness of Flushing as Part of Catheter Maintenance

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***Abstract*— The objective of the study was to develop a robust, reproducible protocol for quantifying the effectiveness of catheter flushing techniques. Institutional protocols vary between institutions with some advocating continuous flushing while others promote pulsatile flushing. Clean in place protocols from other industries suggest that fluid dynamics can significantly improve the effectiveness of catheter cleaning techniques. However, future studies that take a rigorous approach to quantifying the role of factors such as flow rate, Reynolds number, flow pulsatility, or flow volume will require a robust methodology that enables comparisons between flushing procedures and devices. In this study, bovine serum albumin (BSA) concentrations and red blood cell (RBC) counts were used to quantify catheter cleanliness. Two different catheter configurations were loaded using a BSA/RBC mixture or a whole blood soil then flushed using phosphate buffered saline (PBS). The amount of BSA and number of RBCs remaining in and exiting the catheter were measured. Study results showed that counting RBCs provided a statistically significant means of quantifying differences between 10 ml and 3 ml flushes. Furthermore, using RBCs provided both qualitative visual cues and quantitative information without specialized equipment. Future studies could use the findings to develop standardized institutional protocols for catheter maintenance.**

Keywords*— *catheter flushing, pulsatile flushing, vascular access, catheter cleaning, turbulent flushing

I. INTRODUCTION

Venous access is a critical component of patient care, but can increase the potential for complications, such as thrombosis, infection, or morbidity [1]. Intravenous access is used to deliver medication and nutrients, or withdraw blood for analysis. The size and intended use of catheters make them prone to occlusions and microbial colonization so proper catheter maintenance is essential for proper patient care.

A major part of catheter maintenance involves the administration of saline and heparin flushes before and after delivery of medication or nutrients, or removal of blood [2-3]. Saline flushes are administered using either a constant flow rate or a *push-pause* technique, in which the flush is administered for a period of time, paused, then resumed for the remainder of the flush. The push-pause flushing technique may also be referred to as a *pulsatile*, *turbulent*, or *stop-start flushing* technique. Significant variability exists among institutions as to which technique should be implemented for catheter maintenance [2, 4]. The generally accepted rationale for using the push-pause technique among clinical personnel is that pulsatile flows create turbulence and improve catheter cleaning [2, 3, 5, 6]. However, no studies have definitively quantified that turbulence exists or that pulsatile flushing is more effective [7-11].

The fundamental premise of the push-pause technique is similar to the clean-in-place (CIP) practices utilized by the food and agriculture industries [13-16]. CIP is a method of cleaning the interior surfaces of pipes or valves without disassembly. A key element of CIP techniques relies on disturbing the boundary layer near the wall to increase mass or heat transfer and thereby improve cleaning effectiveness [16]. Disruption of the boundary layer can be accomplished by increasing the volumetric flow rate or utilizing a stop-go-stop-go method, similar to the push-pause method. The basic premise is that increasing flow velocity leads to a higher Reynolds number and wall shear stress which can decrease cleaning times even for laminar flows [14, 16, 17]. At high Reynolds numbers leading to turbulent flows, the boundary layer at the wall is thin and can be easily disturbed. When combined with the other inherent properties of turbulent flows, soil is more easily removed.

Studies from other industries [12,14] suggest that flow properties and pulsatile flow can enhance CIP procedures, however, only a small number of studies have been done to date that focus on catheter cleaning procedures. Anecdotal evidence and best practices suggest that higher flow rates, longer flush times, or the push-pause technique enhance catheter cleaning, but only a limited number of studies have sought to quantify the relationship between flush properties and catheter cleanliness. Robust protocols for establishing these relationships are not well defined.

Vigier et al. [8] used a solid soil in a specialized flow chamber to qualitatively show that unsteady flows reduced the time scale of deadhesion of solid deposits

relative to flushing with a steady flow. Visual cues were used to confirm qualitative observations. Results from the study suggested that a pulsed flushing technique could enhance catheter cleaning, but quantitative findings were not presented. Guiffant et al. [9] built on the study done by Vigier et al. to study the efficacy of pulsed versus continuous infusions. In this study, bovine serum albumin (BSA) and fibronectin were passively adsorbed to catheter lumens. Flushing procedures were performed using 10 mL syringes prefilled with normal saline. The amount of albumin recovered from the lumen of the tested devices was used to quantify the efficacy of the flushing procedure. Dead space volumes were not included. Findings from the study suggested that the highest amount of BSA removed for a 10 ml flush volume occurred with a flush time of 2.5 seconds and increasing the flush time to 5 seconds decreased the amount of BSA removed. The authors suggested that increasing Reynolds number increased the percentage of BSA removed and turbulence was likely contributing to the increased removal since the Re exceeded their criteria for turbulence, a Re of 1000. In the study, the highest Reynolds numbers considered were 1270 and 2500 suggesting that Re is indeed an important parameter in catheter cleaning. However, the study did not establish whether the flows were turbulent or only assumed turbulent based on a threshold Re of 1000. Without alternative methods for establishing turbulence, Re between 1000 and 2500 and up to 3500 may be in a transitional regime between laminar and turbulent flows thus further studies are needed to more precisely quantify potential effects of turbulence on catheter cleaning. The findings from Guiffant et al. [9] suggested that the push-pause technique may have effects on catheter cleanliness, but only a limited amount of data was generated and the robustness of the testing protocol was unclear.

A 2018 study by Thandaveshwara et al. [11] obtained conflicting results. In the study by Thandaveshwara et al. [11], pulsed and non-pulsed flushing techniques were used to remove whole blood soils from contaminated peripheral vascular catheter hubs obtained from a clinical setting. The hubs were flushed using 1 ml of normal saline over a period of 60 seconds using either a continuous flush or pulses of 0.2 ml. Red blood cell counts were performed on the washout and used as the means of assessing the effectiveness of the cleaning techniques. In contrast to the results presented by Guiffant et al. [9], the findings from the study suggested that there were no statistical differences in cleaning effectiveness between the pulsed and non-pulsed cleaning methods. However, it was unclear if the initial red blood cell counts in the catheter were known or how much human variability existed in the rate of delivery of the 0.2 ml flushes.

Protocols from the food and agriculture industries suggest that fluid forces could be used to improve the effectiveness of catheter cleaning processes. However, differences in the results reported by Guiffant et al. [9] and Thandaveshwara et al. [11] highlight the need for additional studies to fully quantify how factors such as flow velocity, Re, or turbulence impact catheter cleanliness. Furthermore, there is a need for a robust, repeatable experimental protocol and method of quantifying catheter cleanliness that will allow for comparisons to be made between studies, particularly those involving a broader range of Re or pulsed flows. The current study addresses this need through development of a statistically reproducible experimental protocol that integrates both qualitative visualization as well as quantification of catheter cleanliness using a whole blood soil.

II. METHODS

The overall objective of the study was to develop a robust, reproducible, realistic test protocol for quantifying the effectiveness of catheter flushing. The protocol is an essential step needed to quantify the potential impact of pulsatile flushing on catheter cleanliness. In this study, achievement of statistically significant differences (P value< 0.05) between 3 and 10 ml continuous flushes, two volumes previously shown to result in different levels of soil removal [9], was used to establish robustness and reproducibility.

A solid soil was used as a qualitative indicator of catheter cleanliness by Vigier et al. [8] and Thandaveshwara et al. [11], while Guiffant et al. [9] used fibronectin and BSA to quantify catheter cleanliness. For the current protocol, it was desirable to have both quantitative and qualitative means of assessing cleanliness for comparison. Red blood cells (RBCs), obtained from defibrinated whole sheep's blood, were identified as an additional component of blood that could be easily quantified without specialized equipment and would allow for direct visualization of soil removal. For initial tests, a phosphate buffered saline (PBS)/BSA/RBC mixture was used for the catheter soil. In later tests, only RBCs were used.

Testing was done using Becton Dickinson BD 18 GA 65cm PICC catheters and Becton Dickinson Nexiva catheters. Catheters were initially loaded with 1 mL RBCs combined with 4.5 mg BSA/mL PBS. RBCs were obtained following centrifugation at 4500 RPM for 4 minutes. All catheters were loaded with soil by vertically drawing the soil mixture into the catheter and visually inspecting the catheter and connector to ensure that all dead spaces were filled and no air bubbles were present. The catheters were then placed in a KD Scientific 200 syringe pump for functionalization. Functionalization was done for two hours using the continuous mode for the syringe pump with a volume setting of 0.05 mL and a rate of 0.05 mL/min to maximize the amount of BSA deposited on the catheter surface. An alternate functionalization procedure was utilized with whole blood soil in which the catheters were loaded then allowed to functionalize statically for ten minutes. Mass measurements were used to ensure consistent loading.

To eliminate human variability in the flushing process, all catheters were flushed with 1% PBS at a

prescribed volume and rate using the KDS Scientific syringe pump. Both residue and washout volumes were captured and analyzed. For the purposes of the present study, the volume remaining in the catheter was defined as the ***residue*** and the volume exiting the catheter was the ***washout***. In contrast, the studies by Guiffant et al. [9] and Thandaveshwara et al. [11] only utilized washout measurements. To capture the residue volume after the washout was collected, air was flushed through the catheter and the exiting volume was captured. An additional dead space volume was also observed in the catheter connector even after capture of the residue. The dead space volume was removed manually using a pipette and added to the residue volume. The average volume trapped in the connector was approximately 50 µL, thus exclusion of dead space volumes underestimated residue concentrations by as much as 4-5%.

The concentrations of BSA present in both the residues and washouts were determined using a Thermo Scientific Pierce Bicinchoninic Acid Protein Assay Kit (ThermoScientific, West Palm Beach, FL). Readings were taken using a Spectra Max 190 Microplate Reader (Molecular Devices, Sunnyvale, CA) at a wavelength of 562 nm. Cell counts associated with the residue and washout were determined using standard hemocytometer and cell counting procedures. The cell counting process was partially automated using ImageJ to improve efficiency. Samples were loaded into a hemocytometer then images were digitally captured using a Cooke SensiCam QE attached to an Olympus IX71 inverted microscope. Images from the SensiCam were captured using StreamPix (NorPix Inc., Montreal, Quebec) video capture software. All images were saved then analyzed offline in ImageJ using the Cell Counting plug-in.

III. RESULTS

To establish the robustness of the protocol, preliminary trials were conducted to determine if simultaneous measurement of BSA and RBC concentrations could detect statistically significant differences between a 3 ml and 10 ml catheter flush. Visual inspection of the catheters was used as a supplementary means of assessing catheter cleanliness. Three trials were initially performed using simultaneous measurement techniques to analyze the residue and washout for 3 and 10 ml flushes. In the preliminary trials, higher concentrations of BSA and numbers of cells were generally seen in the 3 ml residue while higher BSA concentrations and numbers of cells were generally seen in the 10 ml washout. The results were consistent with what was anticipated from visual inspection, however inconsistencies with the BSA measurements were observed.

Sample #	3 ml Washout			10 ml Washout		
	Cell Count • 10^{-6}		W/R Ratio	Cell Count • 10^{-6}		W/R Ratio
	Washout	Residue		Washout	Residue	
1	4433	159	28	2860	124	23
2	5267	190	28	5968	411	15
3	4203	306	14	5961	19	318
4	4434	761	6	5143	187	27
5	3627	340	11	11900	143	83
6	4908	305	16	9890	54	184
7	5597	332	17	5341	141	38
8	5866	328	18	3064	114	27
9	5758	251	23	7360	85	87
10	5955	301	20	7340	150	49
11	4303	237	18	4939	31	158
12	4332	246	18	6215	54	115
13	4978	303	16	6497	103	63
14	5077	149	34	7629	464	16
15	4697	211	22	5164	115	45
16	1381	272	5	5720	172	33
Mean ± SD	4676 ± 1104	293 ± 139	18 ± 8	6311 ± 2259	148 ± 123	80 ± 81

Fig. 1. *Comparison of red blood cells found in the residue vs. washout following 3 ml and 10 ml continuous flushes in Becton Dickinson 18 GA 65cm PICC catheters.*

To determine if these inconsistencies were due to the limited sample size or inherent protocol limitations, a larger sample size was implemented. An additional three trials were conducted; however, BSA results remained inconsistent. The washout concentrations consistently showed higher concentrations of BSA, similar to what was observed by Guiffant et al. [9] and the numbers of cells were greater with a 10 ml flush. However, the residue BSA concentrations were also higher with the 10 ml flush while the numbers of cells in the residue were lower. Simple conservation of mass calculations suggested that the BSA results were unrealistic. The results from the cell counting procedure, however, were as expected. Cell counting results showed that more cells were present in the washout following a 10 ml continuous flush (mean

Fig. 2. *Graphical comparison of residue and washout data in Becton Dickinson 18 GA 65cm PICC catheters . More cells are found in the washout following a 10 ml catheter flush than a 3 ml flush while fewer cells are found in the residue following a 10 ml catheter flush than a 3 ml flush. Error bars depict one standard*

number of cells = 6.03 * 109 cells) than following a 3 ml flush (mean number of cells= 4.13 * 109 cells). Fewer cells were also seen in the residue following a 10 ml flush (mean number of cells = 1.57 * 108 cells) than a 3 ml flush (mean number of cells = 2.36 * 108 cells). The results obtained using the cell counting technique indicated the potential robustness of using cell counts, however, the inconsistent measurements from the BSA assay suggested that the simultaneous use of RBC and BSA measurements was not reliable. An additional five experiments were performed in which BSA concentrations were determined separately, however, the BSA assay results were still shown to be inconsistent with great variability between the residue and washout results.

To verify the statistical robustness of the cell counting protocol in quantifying catheter cleanliness,

Sample #	3 ml Washout			10 ml Washout		
	Cell Count • 10^{-6}		W/R Ratio	Cell Count • 10^{-6}		W/R Ratio
	Washout	Residue		Washout	Residue	
1	6910	67	103	7700	35	221
2	6700	44	153	7440	31	243
3	7470	73	102	7580	43	175
4	7030	82	86	7530	48	156
5	6890	121	57	7310	64	114
Mean ± SD	7000 ± 288	77 ± 28	100 ± 35	7512 ± 147	44 ± 13	182 ± 52

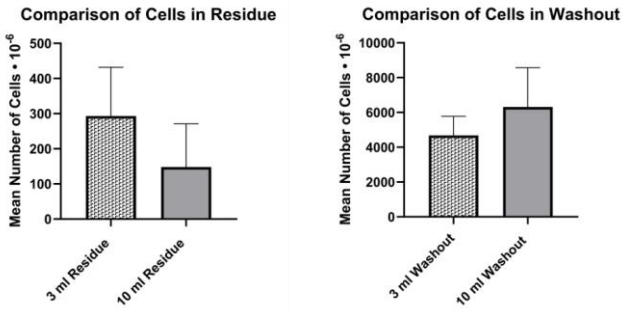
and 10 ml flushes in Becton Dickinson Nexiva Catheters. Unpaired t-test results show that statistically fewer cells are found in the residue from the catheter following a 10 ml flush than a 3 ml flush while more cells are found in the washout following a 10 ml flush than a 3 ml flush. Error bars depict standard deviation.

an additional 10 experiments were done to determine if the protocol could detect statistically significant differences between 3 ml and 10 ml continuous flushes. Figure 1 shows the aggregate raw data obtained from the six original and ten additional trials, while Figure 2 shows a graphical comparison of the results. As seen in Figures 1 and 2, more cells remained in the catheter residue following a 3 ml flush than a 10 ml flush. Also, more cells were present in the washout following a 10 ml flush than a 3 ml flush. A two tailed t-test was performed and a P-value of 0.0142 was obtained using the washout data indicating that the means were statistically different. For the residue data, a P-value of 0.0039 was obtained, indicating that the means were significantly different. Overall, these results indicated that cell counting techniques could be used as an effective means of quantifying catheter cleanliness following flushing procedures.

To further test the robustness of the technique, alternate catheters, BD Nexiva catheters, were introduced and the cell counting protocol was repeated. Five trials were done to confirm that the protocol could discern between a 3 ml and 10 ml continuous flush. Figure 3 shows the raw data comparing 3 and 10 ml flushes and Figure 4 depicts the graphical results. Consistent with results obtained in the PICC catheter, the 10 ml flush yielded more cells in the washout than a 3 ml flush, and fewer cells in the residue. Unpaired t-tests for the washout measurements yielded a P-value of 0.0076 while t-test results for the residue yielded a P-value of 0.0439. The statistical significance further validates the robustness of the cell counting protocol.

The protocol developed in the current study relied on measurement of both the residue and washout cell counts. However, the measurements did not incorporate the starting red blood cell concentrations which could vary between batches of blood. To eliminate the effects of initial cell concentration, the ratio of the number of cells in the washout to the number in the residue (washout/residue ratio) was calculated for each trial. The ratio provided additional information about the relative distribution of cells following a flush and enables direct comparisons between trials with different batches of blood to be made.

To test whether or not washout/residue (W/R) ratios

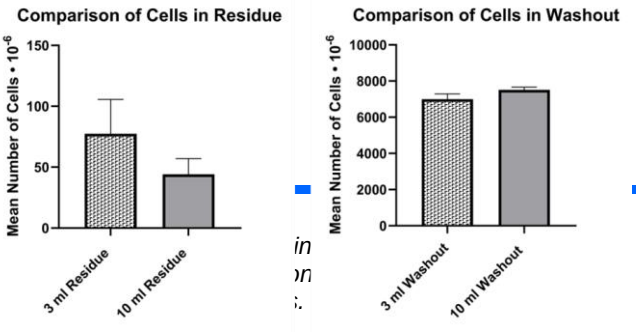


would detect statistically significant differences between a 3 ml and 10 ml flush, the PICC data from Figure 1 was re-analyzed. If a W/R ratio was used to analyze the data in Figure 1, a mean W/R ratio of 18 was obtained for a 3 ml flush while a mean W/R ratio of 80 was obtained for a 10 ml flush. Two-tailed t-test results yielded a p-value of 0.0015, indicating the means are statistically different. For the Nexiva catheter, a mean W/R ratio of 100 was obtained for a 3 ml flush while a mean W/R ratio of 182 was obtained for a 10 ml flush. For the Nexiva catheter, two-tailed t-test results yielded a p-value of 0.0331. The statistical significance suggests that future studies could utilize W/R ratios for quantifying the effectiveness of a flush to eliminate variability in initial cell concentration.

IV. CONCLUSIONS

In this study, the use of BSA concentrations and RBC counts were investigated as possible means of quantifying catheter cleanliness. Data from trials involving BSA were shown to be highly variable, and statistical analysis of the data did not discern significant differences in BSA concentrations following 3 ml and 10 ml continuous flushes. In contrast, the use of cell counting was able to detect statistically significant differences in the number of cells in both the residue and washout in two different types of catheters.

Results from this study indicate both the significance of flush volume and flow rate on catheter cleaning, as well as the effectiveness of the protocol in assessing cleanliness. The findings are consistent with those presented by Guiffant et al. [9], but demonstrate statistical significance relative to differences in the numbers of cells in both the washout and residue volumes. Furthermore, the protocol using red blood cells provided a qualitative visual cue similar to the studies by Vigier et al. [8] and Thandaveshwara et al. [11]. Both quantitative and qualitative findings validated the robustness of the protocol.



The cleaning protocol and choice of soil offer several advantages over previous methods presented in the literature and could be used to robustly quantify the role of factors such as flow rate, pulsatile flow, or turbulence on catheter cleaning. The use of a whole blood soil provides a simpler means for quantifying cleanliness without the need for specialized assays or equipment. Furthermore, the protocol provides quantitative information about where cells are distributed and accounts for cells trapped in dead space volumes to provide a more thorough understanding of the effects of various flow parameters on cleaning. Visual cues also provide a qualitative understanding of the effects of catheter geometry and flow pathways on flushing effectiveness. Washout/reside ratios serve as a standardized measurement parameter to allow for comparisons between soils or catheters in future studies.

Results from this study demonstrate that cell counting can be used as a reliable, robust means of predicting catheter cleanliness. Measurement of both residue and washout concentrations, as well as the use of W/R ratios, provide a holistic view of catheter cleanliness and account for any variability in initial cell count, dead space volumes, hemolysis, or experimentalist variation. Findings obtained using the protocol validate the importance of flow parameters and confirm the need for future studies to further quantify the impact of fluid dynamics on catheter cleaning procedures. Overall, the study provides a reproducible protocol that ultimately could be used to develop standardized institutional protocols for catheter maintenance or aid in catheter design.

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REFERENCES

[1] E. Cheung, M. O. Baerlocher, M. Asch, and A. Myers, "Venous access: A practical review for 2009," *Canadian Family Physician,* vol. 55, no. 5, pp. 494-496, 2009.

[2] L. D. Phillips and L. A. Gorski, Manual of I.V. therapeutics : evidence-based practice for infusion therapy, Sixth edition. ed. Philadelphia: F.A. Davis Company, 2014, pp. xxii, 854 pages.

[3] L. Dougherty and J. Lamb, *Intravenous therapy in nursing practice*, 2nd ed. Oxford, UK ; Malden, MA: Blackwell Pub., 2008, pp. xii, 514 p.

[4] D. Easterlow, P. Hoddinott, and S. Harrison, "Implementing and standardising the use of peripheral vascular access devices," (in eng), *J Clin Nurs,* vol. 19, no. 5-6, pp. 721-7, Mar 2010.

[5] L. C. Hadaway, "Flushing to reduce central catheter occlusions," (in eng), *Nursing,* vol. 30, no. 10, p. 74, Oct 2000.

[6] P. Cotogni and M. Pittiruti, "Focus on peripherally inserted central catheters in critically ill patients," (in eng), *World J Crit Care Med,* vol. 3, no. 4, pp. 80-94, Nov 2014.

[7] R. M. Donlan and J. W. Costerton, "Biofilms: survival mechanisms of clinically relevant microorganisms," (in eng), *Clin Microbiol Rev,* vol. 15, no. 2, pp. 167-93, Apr 2002.

[8] J. P. Vigier, J. Merckx, J. Y. Coquin, P. Flaud, and G. Guiffant, "The use of a hydrodynamic bench for experimental simulation of flushing venous catheters: impact on the technique," *ITBM-RBM,* vol. 26, no. 2, pp. 147-149, 2005/04/01/ 2005.

[9] G. Guiffant, J. J. Durussel, J. Merckx, P. Flaud, J. P. Vigier, and P. Mousset, "Flushing of intravascular access devices (IVADs) - efficacy of pulsed and continuous infusions," (in eng), *J Vasc Access,* vol. 13, no. 1, pp. 75-8, 2012 Jan-Mar 2012.

[10] L. Royon, J.J. Durussel, J. Merckx, P. Flaud, J.P. Vigi er, and G. Guiffant, “The fouling and cleaning of venous catheters: A possible optimization of the process using intermittent flushing”, *ChERD*, vol. 90, no. 6, 803-807, 2012.

[11] D. Thandaveshwara, V. Krishnamurthy, and H.V. Prajwala, “Comparison of Continuous Flush with Pulse Flush Technique in Clearing Blood Contamination of Small Bore Intra Vascular Catheter: A Randomised Control Trial”, *J Clin Diagn Res*, vol. 12, no. 8, sc09-sc11, 2018.

[12] A. Ferroni *et al.*, "Pulsative flushing as a strategy to prevent bacterial colonization of vascular access devices," *Medical Devices (Auckland, N.Z.),* vol. 7, pp. 379-383, 11/07 2014.

[13] W. Augustin, T. Fuchs, H. Föste, M. Schöler, J.-P. Majschak, and S. Scholl, "Pulsed flow for enhanced cleaning in food processing," *Food and Bioproducts Processing,* vol. 88, no. 4, pp. 384-391.

[14] C. Gillham, P. Fryer, A. Hasting, and D. Wilson, "Enhanced cleaning of whey protein soils using pulsed flows," *Journal of Food Engineering,* vol. 46, no. 3, pp. 199-209, 2000.

[15] K. R. Goode, K. Asteriadou, P. T. Robbins, and P. J. Fryer, "Fouling and Cleaning Studies in the Food and Beverage Industry Classified by Cleaning Type," *Comprehensive Reviews in Food Science and Food Safety,* vol. 12, no. 2, pp. 121-143, 2013.

[16] B. B. B. Jensen, "May the force (and flow) be with you: importance of flow in CIP," *Foodsafety magazine,* 2008.

[17] B. B. B. Jensen, M. Stenby, and D. F. Nielsen, "Improving the cleaning effect by changing average velocity," *Trends in food science & technology,* vol. 18, pp. S58-S63, 2007.