

Diana Völz*, Lisa Banzhaf, Tom Toperi, Günther Benderoth

Introducing an Automated Experimental Setup to Evaluate Different Flushing Processes of Leftovers from Parenteral Nutrition in Cannulas

<https://doi.org/10.1515/cdbme-2025-0161>

Abstract: Patients depending on home parenteral nutrition (HPN) must follow a strict procedure for catheter care, as insufficient catheter flushing and hygiene can lead to health risks, including catheter occlusion and infection. Currently, flushing procedures rely on best practice based on experiences passed on from healthcare professional to healthcare professional and no standardized guidelines are given to ensure effectiveness. To address this, this study introduces an experimental setup to evaluate different flushing processes under controlled conditions.

The setup uses a peristaltic pump, that generates flushing patterns with adjustable flow rate, pulsing frequency, and volume. A flow meter records the flushing characteristics for analysis and is used to control the exact volume of flushing liquid used. Each flushing method is assessed by measuring the removal of contamination from the port cannula. Unlike prior studies, that focus on either fat or protein emulsions, this research considers the complete nutrient solution.

This method provides a reliable and reproducible way to evaluate the flushing process and could be used to identify an optimal flushing procedure. Subsequently, this optimal flushing procedure can form the basis for the development of an automatic flushing system that can be integrated into the overall automation process, using only one pump for both parenteral nutrition and flushing of the port catheter. Finding an optimal flushing procedure and developing an automated flushing process can support the standardization in port catheter care, improve patient autonomy and safety and reduce dependency on healthcare professionals for HPN patients.

Keywords: Home Parenteral Nutrition (HPN), port catheter care, Flushing process evaluation, flushing automation, patients' autonomy

1 Introduction

Home parenteral nutrition (HPN) is a time-consuming process that typically lasts up to 14 to 16 hours a day [1]. When administered at night, it disrupts patients' sleep, while during the day patients' social lives are heavily impacted leading to a higher rate of psychological distress [2, 3]. While patients can, in theory, interrupt the daily nutrition therapy and manage the connection, disconnection and flushing of the nutrition system themselves, many feel insecure about the procedure [4], since every interruption can cause health risks. For instance, lipid residues blocking the port catheter could result in a catheter infection. A strict catheter care and sterile working on the catheter system are essential to prevent such complications [5]. It is imperative to avoid microbial contamination of the catheter, particularly during the process of disconnecting infusions.

As a result, patients often rely on clinical visits or professional caregivers for assistance. Enabling patients to perform this process independently would enhance their autonomy and reduce the burden on healthcare professionals [1]. However, patients often struggle to connect the port to the nutrition system on their own. An automated method that ensures an effective and secure flush of the feeding equipment, including the tubing, port cannula, and intravenous port, could reduce the burden on the healthcare system and patients. The aim of this research project is to implement an automated flushing process that performs as well or better than the current manual method carried out by professional caregivers.

In this contribution, an experimental setup is presented that allows evaluating the flushing process by creating various flushing patterns with different characteristics, such as speed, pulsing frequency, interruptions and volume, generated by a programmable peristaltic pump. This liquid flow is then

*Corresponding author: Diana Völz, Frankfurt University of Applied Sciences, Nibelungenplatz 1, Frankfurt am Main, Germany, e-mail: voelz@fb2.fra-uas.de

Lisa Banzhaf, Tom Toperi, Günther Benderoth: Frankfurt University of Applied Sciences, Frankfurt am Main, Deutschland

recorded, the flushing effect is evaluated. In comparison to, flushing patterns manually performed by healthcare professionals are recorded, too. Thus, the setup allows to connect different contaminated devices to test the effectiveness of their flushing automatically and manually.

The setup solves the challenge of finding a reliable and reproducible way to evaluate different influencing factors on the flushing process for different liquid compositions, including protein, carbohydrates and fat emulsions but especially emulsions that include all components.

2 State of the art: port flushing

The AWMF register no. 073/021 recommends that the care of access routes for HPN should be carried out by trained professional caregivers in accordance with evidence-based guidelines and care standards in order to achieve a high quality of hygiene [1]. Standardized guidelines for flushing the port catheter do not exist. Therefore, the traditional knowledge about the best flushing mechanism is passed on from nurse to nurse.

In general, existing studies show that intermittent flushing is more effective than continuous flushing. This is demonstrated in [6] in a study on peripheral catheter irrigation. In [7] it is shown that a pulsatile flushing technique creating turbulent fluid flow is more effective in preventing lumen occlusion than conventional continuous flushing. However, even with pulsing, complete cleaning efficiency is never achieved in these studies [6–10].

Several studies [6–10] have explored the flushing process, primarily using syringe pumps to replicate manual flushing. However, syringe pumps are challenging to program and provide less control over the flushing sequence with view to possible automation in future. As programmable peristaltic pumps are already used for nutrition in HPN, this lends itself to automation for feeding and irrigation in one system.

Furthermore, existing studies typically focus on either fat or protein emulsions rather than a complete nutrient solution that includes both ingredients.

3. Experimental setup

An experimental setup was devised that facilitates and records the flushing process and its characteristics of a programmed peristaltic pump, but additionally allows the recording of manual flushing processes using a syringe. The setup consists

of hardware components and a programmed software environment.

2.1 Hardware components

The experimental setup includes a tubing system connecting the flushing liquid to a peristaltic pump, a flow meter and different end devices. At the moment a port cannula is used as the end device (see Figure 1).

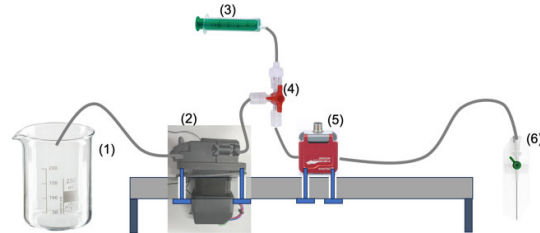


Figure 1: The tubing system sequentially connects the flushing liquid (1) to the peristaltic pump (2), the flow meter (5) and the port cannula (6). A three-valve (4) is used to connect a syringe (3) to record manual flushing.

The peristaltic pump is driven by a step motor that allows the control of the pump in 200 steps per revolution (1.8° per step) with 256 micro-steps per step. The motor operates at speed ranging from 0 to 800 revolutions per minute. A rotor with three rollers to transport the liquid was selected to increase fluid turbulence, which is according to [7] preferable for this experiment. An ultrasonic flow meter is used to measure the volume flow rate. The flow meter was calibrated by the manufacturer to ensure accuracy with the selected tubing.

The tubing system can be used to connect a syringe through a three-way valve. This feature allows the recording of the manual flushing process performed by healthcare professionals to allow a later comparison between the manual and automated flushing processes. The system is controlled using a NI CompactRIO in real-time mode. The NI-9512 actuator module is used with the pump while the NI-9871 serial interface module collects data from the flow meter, including volume flow and total flushed volume.

2.2 Programming

The control program is developed in LabVIEW 18, utilizing the SoftMotion module to generate precise pulse sequences for the stepper motor. This ensures smooth motor operation.

The measurement is controlled by the total flushing volume set at the beginning of each measuring cycle.

2.3 Measurement settings

Since studies [6–10] have shown that pulsatile flushing is more effective than continuous flushing, it is necessary that the flushing process can be customized using various pulse sequences. The following parameters can be adjusted: The peak speed of the pump, the number of peaks in a sequence and the break time between peak sequences. A continuous signal can also be applied. Finally, the total volume of the flushing liquid can be set.

3 Measuring procedure

The measuring process is then divided into different steps.

1. The system including the with nutrient leftover contaminated port cannula must be completely filled with water.
2. The filled port cannula is disconnected and weighed using a precision lab scale.
3. After reconnecting the port cannula, the flushing process is carried out.
4. Finally, the port cannula must be disconnected and weighed again to determine the difference in weight before and after the flushing process, allowing by calculation to determine the amount of contamination flushed of the port cannula.

This approach is subject to error analysis. Depending on the results of this analysis, this approach can avoid the method dyeing nutrients to use spectrophotometry to determinate the effects of the flushing. This method has limitations because each type of dye can only be used for a specific nutrient component like proteins, fats or carbohydrates. This constraint has led prior studies to analyze only selected components rather than complete nutrient solution of parenteral nutrition [9, 10].

Figure 2 shows that the experimental setup can be used to find a reliable and reproducible way to evaluate different influencing factors on the flushing process.

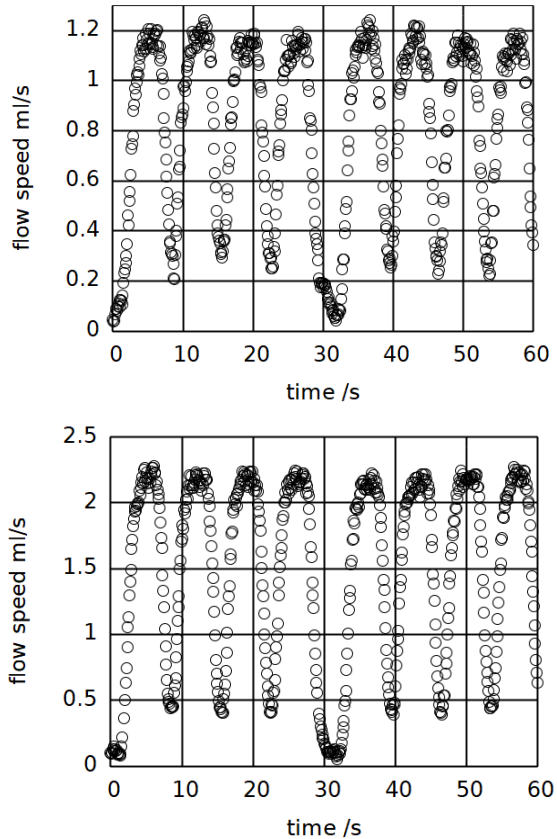


Figure 2: The volume flow rate of two flushing sequences with different characteristics created with the peristaltic pump were measured with the flow meter. The figure shows that the sections of acceleration are obviously linear. For both speeds the fluid flow is laminar. At sections where there is a break or the direction of the acceleration is turned, there is turbulence of the fluid. Thus, these sections can be varied in magnitude and speed, to find an algorithm for an optimized flushing procedure.

4 Conclusion

Initial test runs showed that the presented setup can accurately facilitate and record a flushing process. Thus, a fully automated method for evaluating various flushing sequences has been successfully developed. This system provides a reliable and reproducible way to assess various influencing factors in the flushing process. Additionally, it allows for testing different liquid compositions, including protein and fat solutions.

Since the peristaltic pump can operate bidirectionally, a push-pull flushing pattern can also be implemented, potentially improving flushing efficiency. The system is now available for further optimization of the flushing process using

experimental design approaches to evaluate automated flushing performance. In a next step, selected experts in healthcare with different levels of knowledge will carry out flushing processes. Such flushing can be then compared with automated flushing.

Author Statement

The authors gratefully acknowledge the financial support provided by the B. Braun Foundation (www.bbraun-stiftung.de) for this research project. The B. Braun Foundation operates independently, and thus no conflicts of interest exist regarding this support.

References

- [1] Bischoff SC, Arends J, Dörje F, Engeser P, Hanke G, Köchling K, Leischker AH, Mühlebach S, Schneider A, Seipt C, Volkert D, Zech U, Stanga Z, DGEM Steering Committee. S3-Leitlinie der Deutschen Gesellschaft für Ernährungsmedizin (DGEM) in Zusammenarbeit mit der GESKES und der AKE: Künstliche Ernährung im ambulanten Bereich. *Aktuel Ernährungsmed* 2013;38:101–154.
- [2] Malone M. Longitudinal assessment of outcome, health status, and changes in lifestyle associated with long-term home parenteral and enteral nutrition. *JPEN J Parenter Enteral Nutr* 2002;26:164–168.
- [3] Messing B, Landais P, Goldfarb B, Irving M. Home parenteral nutrition in adults: a multicentre survey in Europe. *Clin Nutr* 1989;8:3–9.
- [4] Ayen E, Goulet O, Talbotec C, Poisson C, Rocha A, Brion K, Madras MB, Eicher I, Martinez I, Bego C, Franck-Luquet D, Godot C, Chasport C, Lambe C. An innovative educational program for adolescents on home parenteral nutrition: “the connected ados”. *Transplantation* 2023;107:41–41.
- [5] Tempel K. Lebensqualität unter langfristiger heimparenteraler Ernährung, Dissertation at Charité Universitätsmedizin. Berlin 2009.
- [6] Ferroni A, Gaudin F, Guiffant G, Flaud P, Durussel JJ, Descamps P, Berche P, Nassif X, Merckx J. Pulsative flushing as a strategy to prevent bacterial colonization of vascular access devices. *Med Devices (Auckl.)* 2014;7:379–383.
- [7] Guiffant G, Durussel JJ, Merckx J, Flaud P, Vigier JP, Mousset P. Flushing of intravascular access devices (IVADs) - efficacy of pulsed and continuous infusions. *J Vasc Access* 2012;13:75–8.
- [8] Royon L, Durussel JJ, Merckx J, Flaud P, Vigier JP, Guiffant G. The fouling and cleaning of venous catheters: a possible optimization of the process using intermittent flushing. *Chem Eng Res Des* 2012;90:803–807.
- [9] Okamura N, Yamato T, Yamaoka I, Doi K, Koyama Y. How to perform appropriate flushing after lipid emulsion administration using totally implantable venous access devices in longterm total parenteral nutrition and home parenteral nutrition. *Clin Nutr ESPEN* 2021;41:287–292.
- [10] Okamura N, Yamaoka I. A comparison of effects of pulsatile and bolus flushing methods on lipid emulsion residues that lead to bacterial growth in intravenous catheters. *J Vasc Access* 2023;25:1320–1327.