International Journal of Nursing Studies 68 (2017) 73–82

Contents lists available at ScienceDirect

International Journal of Nursing Studies

journal homepage: www.elsevier.com/ijns

Effect of venepuncture process design on efficiency and failure rates: A simulation model study for secondary care

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ARTICLE INFO

Article history:
Received 4 July 2016
Received in revised form 4 November 2016
Accepted 24 December 2016

Keywords:
Blood sample
Haemolysis
Simulation modelling
Venepuncture

ABSTRACT

Background: Healthcare aims to deliver good patient outcomes. For many clinical procedures there are multiple alternative task sequences that can be performed. These deviations can influence procedure reliability, efficiency of usage of hospital resources and risk to staff and patient safety. Venepuncture is one of the most common invasive procedures in healthcare. Literature of clinical practice shows evidence of wide variability in the procedure order and the duration of each step, which can depend on attributes, such as patient health, sampling method and staff skills.
Objective: To use a computer simulation model based on Petri nets to evaluate the impact on outcomes of commonly practiced deviations from the venepuncture procedure guideline and variations in key dependent variables. The outcomes considered include the probability of successfully obtaining a blood sample and the procedure completion time.
Design: A computer simulation model was constructed using the Petri net technique which mimics the different variations of the venepuncture procedure. Qualitative and quantitative data for the model was collected from the literature and through interviews and questionnaire responses from doctors and phlebotomists. Statistics on the reliability and duration for different variations were then calculated from the model output.
Setting: A digital laboratory to model venepuncture in secondary care.
Results: The model showed that the common practice of applying the tourniquet prior to vein identification and releasing it after sample tubes are filled may result in a ten-fold increase in sample haemolysis, compared to the recommended guideline procedure. Equipment layout on wards and patient vein prominence were identified as the two most important factors influencing time efficiency of blood sample collection.
Conclusions: Petri net computer models were shown to be an effective method for evaluating the success rate and completion time of the venepuncture procedure under alternative task sequences and variations in key dependent variables. The results obtained from the model showed a significant increase in the rate of sample laboratory rejection due to haemolysis when commonly practiced deviations from the guideline procedure were performed. The rate of failure to collect a sample and the mean time for performing the procedure increased significantly for patients with less prominent veins and when the procedure was performed on unfamiliar wards. These results highlight the need for healthcare providers to ensure guidelines are followed when performing venepuncture, equipment layouts are standardised across locations and that the vein prominence of different patient groups is considered when allocating resources for blood sample collection.

What is already known about the topic?

- Venepuncture is one of the most commonly performed clinical procedures and successful, efficient blood sample collection is important for both patients and staff.
- There are many variations in how the venepuncture procedure is performed in practice and these may result in a suboptimal outcome.
- Simulation modelling using Petri nets has been widely used in reliability engineering to analyse outcomes and efficiency of maintenance procedure designs, but has not previously been developed for clinical procedures.

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http://dx.doi.org/10.1016/j.ijnurstu.2016.12.010
0020-7489/

What this paper adds

- Deviations from venepuncture procedure guidelines, that are common in practice, can result in a significant increase in blood sample haemolysis and laboratory rejection.
- Demonstrates the impact on outcomes and efficiency of different variations in the venepuncture procedure, using Petri net based simulation modelling.

1. Introduction

The World Health Organisation (WHO) report numerous studies showing that major complications due to preventable adverse events during clinical procedures are common (WHO, 2009). The ability to analyse the impact on the efficiency and probability of successful outcomes of a clinical procedure from deviations in the task sequence, variations in dependent variables and resource availability could reduce the risk of harm to patients and staff, and improve procedural outcomes. In addition, it would help healthcare providers use available money more efficiently and reduce patient waiting times through optimal use of resources and removal of process bottlenecks (Bayer, 2014).

According to the Institute to Healthcare Improvement applying reliability assessment techniques in healthcare can help to reduce failures, increase its consistency and improve patient outcomes (Nolan et al., 2004). These techniques have been widely applied for setting safety and reliability standards in system design, operation and maintenance (Amalberti et al., 2005). One of the traditional methods used in industry is the approach of probabilistic risk assessment, originally developed for improving safety of nuclear plants (Vesely, 1970), and later applied in many different settings ranging from aerospace (Frank, 1995) to process industry (Kelly and Lees, 1986). Such methods help the analyst to understand complex systems as a whole and they can be used to identify causes, severity and frequency of failures. Only a very limited number of publications appear on reliability analysis of clinical procedures, for example, estimating surgery risks (Zixian et al., 2011).

The objective of this study is to demonstrate the applicability of Petri net modelling (Wang, 1998) to the analysis of clinical procedures. Petri nets offer a graphical and mathematical notation for modelling stepwise procedures that include choice, random step outcomes, random step durations, iteration and concurrent execution. They enable task durations and outcomes to be simulated to efficiently analyse the procedure outcomes. Petri nets are widely used in reliability engineering (Schneeweiss, 1999) to model system failures and the application of maintenance procedures, for example, the authors in Reed et al. (2013) used the technique to model maintenance procedures within the service support system of a functional product. Clinical procedures have many similarities with maintenance procedures performed on equipment in industry. They both consist of the application of often complex sequences of tasks by trained personnel to restore or maintain the physical condition of an object. Therefore, the Petri net modelling technique is potentially a useful tool for analysing clinical procedures. No publications demonstrating the use of Petri nets for modelling clinical procedures were found in the literature, although they have been used previously for modelling other aspects of healthcare, such as patient flows in medical services (Xiong et al., 1994).

Venepuncture, the process of obtaining a blood sample through puncture of a vein, is one of the most common invasive procedures in healthcare (WHO, 2010), and it was chosen as the clinical procedure to be analysed in this study. The specific objectives related to venepuncture are to use a computer simulation model based on Petri nets to evaluate the impact on outcomes, such as the probability of successfully obtaining a quality blood sample and the procedure completion time, of commonly practiced deviations from the guideline venepuncture procedure and variations in key dependent variables.

2. Methodology

The proposed methodology is described in this section.

2.1. Definitions

The reliability of a clinical procedure is defined as the probability that a blood sample is successfully obtained from a patient by a healthcare provider at the first attempt. The completion time of the procedure performance is defined as the duration of the procedure from initiation of the first task to completion of the last task.

2.2. Data collection

To better understand the venepuncture process, a review of related literature, including practitioner guidelines and research papers, was conducted. Interviews with two secondary care doctors and two phlebotomists, each lasting around 30 min, were then carried out to obtain further qualitative data relating to the venepuncture procedure in practice. During the literature review, a total of 40 relevant documents were found and examined, which gave a general understanding of the procedure, factors influencing its reliability, and task durations.

The data from the interviews, together with the data from the literature review, was used to formulate appropriate questions for a questionnaire, suitable for obtaining quantitative data necessary for the model construction. The quantitative data that was sought for included task durations, the proportion of healthcare providers that in practice carried out specific deviations in the task sequence from the ones described in the guidelines, and task failure rates. A questionnaire that could be accessed through the internet consisted of 40 questions and it was distributed to doctors working at two UK hospitals (1688 and 96 doctors work in the two hospitals respectively). It contained questions about the average duration and its variation of each task, the order of tasks and the probability of failing the task of obtaining a blood sample in a single attempt. Further detail of the questionnaire can be found in Appendix A.

The two secondary care staff categories, i.e. doctors and phlebotomists, were chosen due to their expression of interest in this study and availability to participate in the interviews and fill out the questionnaires. The doctors who were interviewed and participated in the study were junior doctors, who have been qualified for one year and they carry out around three venepunctures a day. The two phlebotomists had over ten years of experience and performed around 50 venepunctures a day.

As confirmed by the ethics committee at the University of Nottingham, ethics approval for the study was unnecessary, as the healthcare providers were not subjects of research and they were participating outside their normal workplace.

2.3. Model construction using Coloured Petri nets (CPN)

A simulation model was constructed using Petri nets, a graphical tool that can be used to model the dynamics of many types of system (Schneeweiss, 1999). A Petri net model represents the states that a system may be in and the transitions between these states using a directed bipartite graph in which nodes represent either a transition or place, shown in diagrams as unfilled rectangles and circles respectively. Directed arcs link