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Reducing errors in the administration of medication with infusion pumps in the intensive care department: A lean approach

Alexander F van der Sluijs[1], Eline R van Slobbe-Bijlsma[2], Astrid Goossens[3], Alexander PJ Vlaar[1] and Dave A Dongelmans[1]

Abstract

Background: Medication errors occur frequently and may potentially harm patients. Administering medication with infusion pumps carries specific risks, which lead to incidents that affect patient safety.

Objective: Since previous attempts to reduce medication errors with infusion pumps failed in our intensive care unit, we chose the Lean approach to accomplish a 50% reduction of administration errors in 6 months. Besides improving quality of care and patient safety, we wanted to determine the effectiveness of Lean in healthcare.

Methods: We conducted a before-and-after observational study. After baseline measurement, a value stream map (a detailed process description, used in Lean) was made to identify important underlying causes of medication errors. These causes were discussed with intensive care unit staff during frequent stand-up sessions, resulting in small improvement cycles and bottom-up defined improvement measures. Pre-intervention and post-intervention measurements were performed to determine the impact of the improvement measures. Infusion pump syringes and related administration errors were measured during unannounced sequential audits.

Results: Including the baseline measurement, 1748 syringes were examined. The percentage of errors concerning the administration of medication by infusion pumps decreased from 17.7% (95% confidence interval, 13.7–22.4; 55 errors in 310 syringes) to 2.3% (95% confidence interval, 1–4.6; 7 errors in 307 syringes) in 18 months ($p < 0.0001$).

Conclusion and Relevance: The Lean approach proved to be helpful in reducing errors in the administration of medication with infusion pumps in a high complex intensive care environment.

Keywords

Pharmacoepidemiology/drug safety, critical care/emergency medicine, patient safety, medication safety, lean

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Introduction

Ever since the publication of the ground-breaking report by the Institute of Medicine (IOM), ‘to err is human’[1] the focus on quality of healthcare has been growing. A study about errors in a tertiary care academic medical centre demonstrated that the highest rate of adverse events was observed in medical intensive care units (ICUs; 19.4 per 1000 patient-days) compared with medical or surgical general care units (10.6 and 8.9 per 1000 patient-days).[2] We hypothesized that in our 32-bed mixed ICU in a university hospital, this rate would not be different. Of all reported incidents in our intensive care (ranging from 1500 to approximately 2500 per year), a large part (30%) is medication related. We consider every unintended or unwanted event concerning patient care an incident, regardless if it harmed the patient or only may have done so (near-miss).

[1]Department of Intensive Care Medicine, Academic Medical Center, Amsterdam, The Netherlands
[2]Department of Intensive Care Medicine, Tergooi Hospitals, Hilversum, The Netherlands
[3]Department of Care Support, Academic Medical Center, Amsterdam, The Netherlands

Corresponding author:
Alexander F van der Sluijs, Department of Intensive Care Medicine, Academic Medical Center, Room C3-215, Meibergdreef 9, 1105 AZ Amsterdam, The Netherlands.
Email: a.f.vandersluijs@amc.uva.nl

Medication errors are a well-known problem in the delivery of healthcare.[3] We decided to focus specifically on infusion pumps (also known as syringe drivers) since the professionals on our ward observed that a large part of the medication errors are associated with administering medication from syringes using infusion pumps. Administration errors and discrepancies with infusion pumps are common[4] but do not cause harm in the vast majority of cases.[5] Previously, both technical and behavioural interventions were attempted to reduce medication errors with infusion pumps. In a large multi-hospital before-after observational study, the introduction of an intervention bundle was successful in reducing overall and medication error rates, but some errors remained and there was no reduction in potential harmful errors.[6] The use of smart pumps may reduce errors, but further development is needed.[7,8]

In our ICU, Perfusor® Space infusion pumps are used (B. Braun Melsungen AG, Melsungen, Germany). These (smart) syringe infusion pumps contain a digital medication library, which can be customized by institutions according to available medication and concentration preferences. After a syringe with intravenous medication is inserted in the infusion pump, the name of the medication can be selected from the digital library and this is subsequently displayed on the screen of the pump, together with the actual infusion rate in millilitres per hour. Common errors in our ICU consisted of lacking (written) data on the syringe label such as expiration date or a double signature, but we also noticed discrepancies between the medication in the syringe and the display of the infusion pump, or non-corresponding documented and actual infusion rates. Since many efforts to reduce incidents using infusion pumps had failed in the past (personal feedback, team sessions, posters with results, recurrent clinical lessons and newsletter items), we hypothesized that the Lean approach could help us to reduce incidents in the administration of medication with infusion pumps.

The Lean philosophy is used to improve processes and reduce errors. Lean was originally developed as a production philosophy and quality system.[9] It is mainly derived from the Toyota Production System (TPS). In the processes of this production system, 'waste' was eliminated and value was added. Paying attention to little problems turned out to be the most efficient way to build cars.[10] Virginia Mason, a large hospital system, adapted this strategy and developed Patient Safety Alerts.[11] Toussaint and Gerard[12] identified in their book 'On the mend' the eight wastes and translated them into healthcare problems (Table 1). Although the review of Moraros et al.[13] concluded that there is no evidence on the benefit of Lean in hospitals, there are some studies that support the use of Lean in healthcare.[14,15]

Despite the limited evidence for using Lean in hospitals[13,16] we chose this approach, because our hospital provided Lean coaches as a pilot. Furthermore, preliminary results in other hospitals suggested Lean to be beneficial in an ICU setting. We wanted a quality improvement method to challenge the healthcare providers involved to figure out themselves what the causes of the errors with infusion pumps were and how to improve in a sustainable manner. In Lean terms, techniques to prevent or detect defects are called mistake proofing.[9,10] With the Lean approach we aimed to reduce the number of errors, concerning the administration of medication by infusion pumps, by 50% in 6 months. Besides improving quality of care and patient safety, we wanted to determine the effectiveness of Lean in healthcare.

Methods

We used Lean to address medication administration errors related to the use of infusion pumps. This before-and-after observational study was performed in a 32-bed mixed medical-surgical ICU of a tertiary care university hospital in The Netherlands. The ICU is a 'closed format' department in which patients are under the direct care of the ICU team consisting of intensivists, subspecialty fellows, residents and specialized nurses. Approximately 40% of the patients are post-cardiac surgery patients; the remainder consists of a wide variety of patients, including trauma, neurosurgery and sepsis patients. Most patients are treated with two to eight medications delivered by syringe pumps at the same time. Medication prescription is done in a PDMS (patient data management system; MetaVision, Itémedical, Tiel, The Netherlands). The PDMS consists of an electronic medical record (EMR) including Computerized Physician Order Entry (CPOE) and automatically collects data from the patient monitor, the ventilator and other connected hardware. Medication orders are placed by the physicians and sent to the nurse at the bedside and to the pharmacy. Our pharmacy is a satellite hospital pharmacy: it consists of a dedicated team, which has a small facility on the ICU. The pharmacy is responsible for the production and distribution of all medication, including prepared syringes. Specialized intensive care nurses are responsible for correct administration.

After recognition of infusion pumps as a possible target for improvement, a baseline measurement of error rates was performed. The baseline measurement demonstrated there was indeed room for improvement. In 17.7% (55 errors in 310 syringes) of the syringes in infusion pumps, there was an error. These errors varied from a lacking co-signature, a missing expiration date/time till 'past expiration date' or wrong type of medication. Prescription errors were not included in this study. We aimed at a 50% reduction of syringe pump errors in 6 months (to accomplish an error percentage $<10\%$). The first action was to request help from the hospitals Lean team by delivering a Lean coach to support our efforts. The Lean coach is a formally trained employee who supports the introduction of Lean and Lean projects in hospital departments. From the entire ICU team (doctors and nurses) a working group was formed, consisting of three intensive care nurses, three senior intensive care nurses and two intensivists. Hereafter, this working group is called the Lean team.

Table 1. Comparison of application of Lean management in manufacturing and healthcare organization.

Type of problem	Manufacturing organization	Healthcare organization	Implication for intensive care
Overproduction	Producing ahead of need	Unnecessary treatment, overuse of diagnostic testing	Clear treatment goals and end-of-life decision guidelines
Waiting	Operators standing idle waiting for other workers or machines to finish	Patient waits for an appointment, for test results, for a bed, for discharge paperwork	Clear admission and discharge guidelines
Transport	Moving parts and products unnecessarily	Taking patients to and from tests, moving patients from one room to another	Diagnostic tests being performed bedside
Over processing	Performing unnecessary or incorrect activities	Unnecessary forms, asking the same patient the same question more than once, charting everything instead of charting by exception	Digital system preventing re-enter of patient data Patient centric rounding
Inventory	Having more than the minimum stock necessary	Overstocked drugs that expire, under stocked surgical supplies that lead to delays while staff search for them	Pooling of inventories within the hospital or even within the region Just in time
Motion	Making workers look for parts, tools, documents, etc.	Searching for supplies, forms, drugs	Correct and logic labelling of all supplies, forms and drugs
Defects	Inspection, rework, scrapping parts that do not meet standards	Making and correcting errors, checking for errors	Clear protocols including feedback mechanisms and e-alerts
Talent waste	Failure to listen to employee ideas for improvement	Using highly trained individuals to do jobs that could be performed by less expensive personnel, failure to listen to employee ideas for improvement	Focus on ICU-physician and ICU-nurse specific tasks and outsource tasks such as washing patients, paperwork and move tasks down from ICU-physician to ICU-nurse when possible

Source: After Toussaint and Gerard.[12]
ICU: intensive care unit.
In Table 1, the comparison between industry, healthcare and intensive care is made. This is done per type of waste according to the Lean philosophy.

The actual process of delivering medication using a syringe pump was captured in a value stream map, showing all the necessary steps in the process. For every step, causes for disruption of the process were identified. The Lean team then invited all employees to comment on the value stream map and its most vulnerable sub-processes. An important conclusion was that all described steps were perceived as necessary in the process of medication administration using syringe infusion pumps. Most steps on the value stream map, however, were considered vulnerable to error. These errors varied from forgetting things, skipping (sub) steps, mixing up two similar processes to deliberately not performing a specific task.

With the additional input of the employees, we eventually identified three main causes why the process or a step within was not performed in the way it was supposed to. These were lack of time, distraction and dissonant behaviour. As said, the first cause was a perceived lack of time. During a shift, nurses are under a lot of pressure performing those tasks that are necessary to care for critically ill patients. In general, one nurse cares for two patients, continuously shifting attention between both. When medication syringes are changed, the policy describes a double check by another person. Finding another nurse to change a syringe costs time and effort. The second cause was distraction. Hospital staff is asking questions or talking to the person who is preparing and administering medication and who needs undivided attention to perform that task. Besides colleagues, also patients or relatives are having conversations with nurses during the preparation or administration of medication. The third cause was dissonant behaviour and has to do with culture. Although it is clear that safe handling of medication in a complex high-risk environment like the ICU is one of the keystones in delivering high-quality care, people who are able to take 'unsafe' shortcuts in this process will use these. If these shortcuts become routine and perceived as acceptable, a major problem in the safe delivery of care has become a fact.

The Lean team was asked to think about which countermeasures had to be taken to eliminate the root causes for errors with the administration of medication with infusion pumps. Actions/interventions that were taken are discussed in the 'Results' section.

The progress of the undertaken countermeasures was discussed twice a week during a stand-up meeting of 15 min.

All available team members working on a day shift joined these interactive stand-up meetings. The activities of the Lean team were presented, steps of the value stream map and underlying causes were discussed and eventually countermeasure implementation was announced or given feedback on. On average, between 7 and 20 employees were present. Because the study eventually lasted 18 months, we assume that almost every ICU employee attended one of more stand-up meetings when the issue of the medication administration with syringe infusion pumps was discussed. Moreover, the interim results and implementation of abovementioned actions were shared by clinical lessons, instructions, emails and a 'Lean' newsletter. The Lean philosophy describes that a team is not formed 'top-down' but 'bottom-up'.

We chose to measure the impact of the interventions by performing unannounced sequential audits. We assessed whether or not the number of errors using syringe pumps were reducing over time. Auditors were senior ICU nurses who as a part of regular audits on various topics also audited the syringes. In total, three nurses performed the audits. The auditors were as members of the ICU team also involved in Lean but were not part of the implementation working group (Lean team). During an audit, all patients admitted on the intensive care were visited and every infusion pump with a syringe in it was evaluated and checked for five possible errors (see below). The number of errors in relation with the number of syringes checked was a measure for the success of the Lean approach. The approach used to establish whether the observed outcomes were due to the intervention was the following: the stand-up meetings were used to evaluate whether or not the interventions had been applied. In over 20 Lean sessions, the interventions were discussed whereby in small PDCA (Plan Do Check Act) cycles[17] the bottlenecks were mentioned.

Measurements

To measure if there was any improvement, we choose to perform unannounced audits by senior nurses. The auditors were instructed and used objective predefined criteria to limit inter-observer variability. The post-intervention data were collected in the same way the baseline measurement was performed. In every audit, we checked the syringes for five possible errors:

1. Correct dose?

Was the syringe dispensed with the right concentration and dose of the medication according to the prescription?

2. Correct medication?

Was the syringe filled with the right medication? That is, comparing the prescribed medication with the syringes were there differences between prescribed and actual given? Another important issue concerning the correct medication was the correspondence of the medication displayed on the syringe infusion pump with the medication in the syringe. When the medication in the syringe differed from the name displayed, this was obviously considered an error. If a prescription, an infusion pump display and the syringe involved three different medications, then this would count as two errors.

3. Correct rate of administration?

Was the pump running at the prescribed rate? When medication with changing infusion rates was used: did the documented infusion rate in the EMR correspond with the actual infusion rate? There was no electronic coupling between the infusion pumps and the EMR.

4. Correct route of administration?

Was the medication given at the prescribed site, that is, intravenous central versus intravenous peripheral (or otherwise)?

5. Correct expiratory date?

Was the syringe provided with an expiration date/time and was the syringe not expired. An error was counted when there was no expiration date on the label or if there was an expired date/time.

The rationale for choosing audits instead of relying on incident reports was that there is a well-known reporting bias in incident reporting.[18] Either underreporting due to numerous reasons such as lack of time, lack of sense of urgency or relative over-reporting occurs when attention is given to a specific subject. Lack of a clear denominator is another problem encountered using incident reporting. In our department, the incident reporting system is used to determine improvement project priorities; the number of reported incidents is not used to estimate the effect of interventions.

Statistical analysis

A chi-square test was used to calculate the differences between percentages whereby the percentages before the implementation of the countermeasures were compared to those after the implementation. The numerator is the number of errors and the denominator the number of syringes checked.

Results

After baseline measurement, the value stream map exposed three main underlying causes for errors in administering medication by infusion pumps: lack of time, distraction and dissonant behaviour. Eventually two important countermeasures were implemented:

Table 2. Audit measurement results.

Measurement (month)	Error in dose	Error in medication	Error in speed	Error in administration route	Error in expiration date	Total errors	Number of patients	Number of syringes	Percentage of errors
June (baseline)	8	3	8	4	32	55	96	310	17.7
November	2	4	8	1	5	20	36	180	11.1
January	3	1	4	0	41	49	103	332	14.8
May	1	2	14	0	3	20	61	254	7.9
August	0	10	8	0	1	20	87	365	5.5
January	0	1	3	0	3	7	98	307	2.3*
Total overall	14	21	45	5	85	171	481	1748	

Per month the number of checked syringes, number of patients, number of errors per category and total errors are displayed. The percentage of errors represents the number of errors divided by the number of syringes × 100.
*$p < 0.0001$ compared to baseline.

1. There was no clear standard on the ward on how to change the syringes in the infusion pump. So a standard operating procedure was introduced regarding the connection of newly prescribed medication, delivered by a syringe infusion pump as well as changing syringes of medication already being delivered. The standard operating procedure states that changing syringes is always performed by two nurses. This standard procedure was introduced several weeks after our first (baseline) measurement audit.
2. A fixed dedicated moment of time was introduced to double check the medication, co-sign and to change the syringes in the infusion pumps. This dedicated moment of time was every 2 h, on the hour, for 10 min (e.g. from 10-10.10 h). Two nurses performed this procedure together for their patients. Syringes expected to be empty within the next 2 h, according to the remaining content and actual infusion rate, were changed preemptively. Other ICU employees (e.g. doctors) were taught not to disturb the nurses during this process. Relatives of patients were also involved by education. Telephone calls were responded by a nurse who was not involved in the medication check. Only urgent alarms could interrupt the process. Implementation of this countermeasure started 1 month prior to the second measurement audit (5 months after baseline measurement).

Audit results

A total of 1748 syringes were audited in six separate measure moments, consisting of multiple sessions in a particular month, used in 481 patients (Table 2). The first measure month was the baseline measurement. Initially, we aimed to reduce the number of errors by 50% in 6 months and planned audits after 3 and 6 months. Eventually the first audit after baseline measurement was performed after 5 months because we wanted to measure the effect of both implemented countermeasures. The following measurement was after 7 months. The study was prolonged because we measured an initial decrease in infusion pump-related medication errors while at the same time our stand-up sessions learned that our nurses needed more time to get used to the new process. The interval between the fifth and last measurement was prolonged because of logistical reasons.

The mean number of syringes during audits was 3.6 per patient. The minimum number of patients audited in one session was 36 with 180 syringes. The maximum was 103 patients with 332 syringes. The error that was observed most was that a syringe was still connected although the past-expiration date and time was reached (85 of 171 errors = 50%). The least common error was a syringe connected to the wrong infusion route (5 of 171 errors = 3 %). Over a period of 18 months, the overall percentage of errors decreased from 17.7% (95% confidence interval (CI), 13.7–22.4; 55 errors in 310 syringes) to 2.3% (95% CI, 1–4.6; 7 errors in 307 syringes). This difference of 15.4% points was statistically significant (95% CI, 11–20), $p < 0.0001$. In Figure 1, the overall and categorized percentage of errors over time is shown. The total of errors gradually reduced over a period of 18 months. Focusing on the types of errors, it is noticeable that the past expiration date errors fluctuated during the study.

Discussion

The key finding is that the Lean approach to deal with a quality problem in the delivery of healthcare can work. Initially, we noticed that there was hesitation in the ICU team regarding Lean, which was partly due to the time investment in relation to the paucity of evidence. Hesitation among employees gradually diminished when interim results of this project were presented. We showed a reduction in errors in the use of infusion pumps from 17.7% to 2.3%. We chose to describe the intervention in enough detail that one can understand what was done. It is imperative that as with much of the work done in patient safety that the context plays a major role.

Relation to other literature

Additional justification for performing our study is the fact that the systematic review from Moraros et al.[13] did not find evidence regarding improved patient satisfaction and

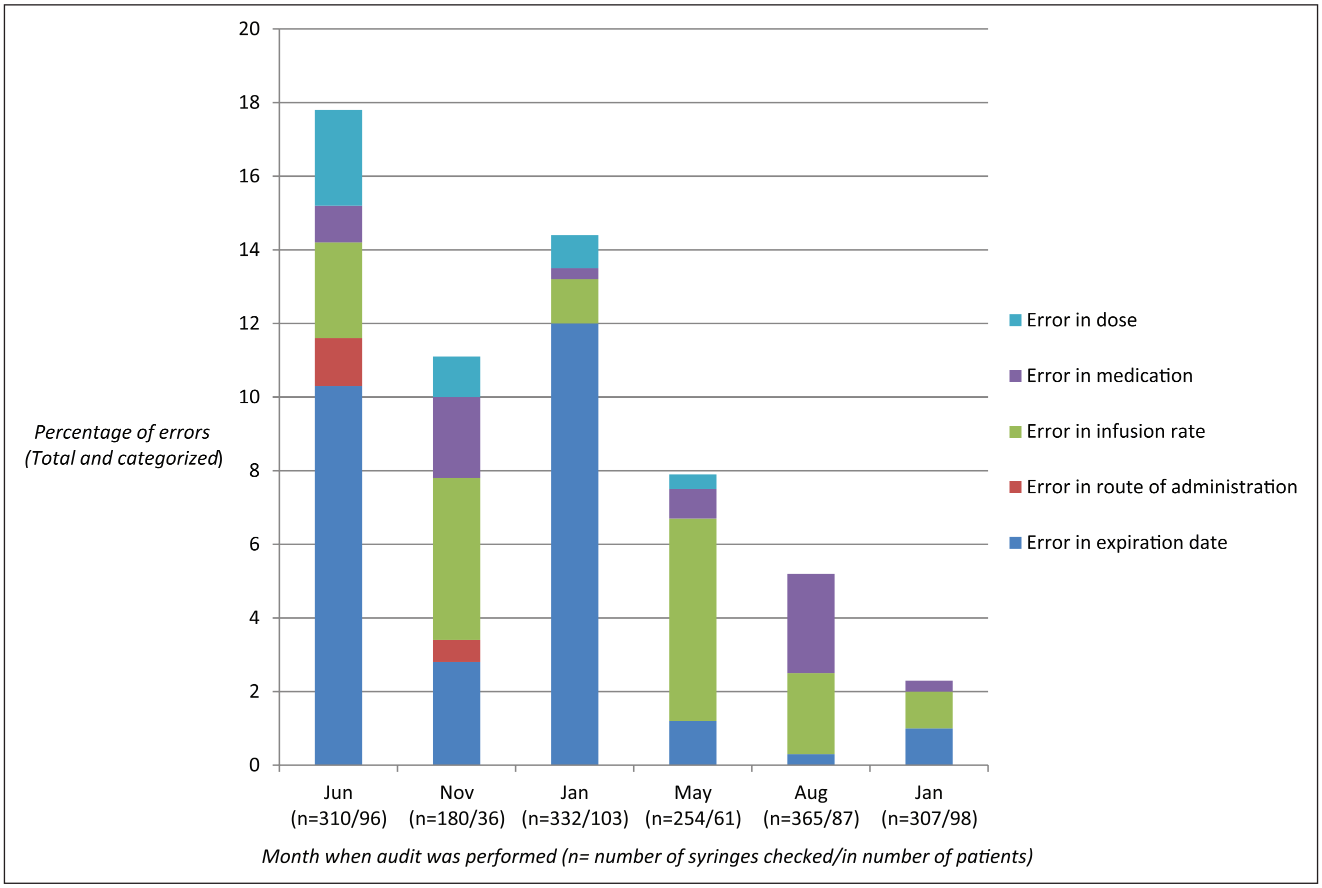

Figure 1. Overall and categorized percentages of medication errors over time.
Y-axis: percentage of errors by type of errors over time. X-axis: month when audit was performed (n = number of syringes checked/in number of patients).

outcomes but mixed results on safety outcomes. In contrast to their conclusion that there is insufficient evidence to support Lean in healthcare settings, thereby discouraging the use of Lean, we may have demonstrated a positive effect of the Lean approach on our unit in this project. The intensive care environment is different compared with the context in many other studies in the systematic review, but is hard to establish how that contributed to our positive results. One explanation could be that engagement of the entire team towards Lean is essential to be successful. In the ICU environment, the work is already team based which may have facilitated implementation and embracement of Lean. At the same time, it must be said that using other methods to improve quality (Healthcare Failure Mode and Effect Analysis (HFMEA), Tripod or root cause incident analysis or continuous improvement) could have resulted in the same outcome. In the same study,[13] it is also stated that there is a potential but inconsistent effect on process outcomes like patient flow or safety. We showed that there is a potential effect on patient safety by significantly reducing the number of errors with the administration of medication with infusion pumps. Our results are supported by a number of reports from paediatric settings.[14,15] In a recent paper, Lean was considered a powerful process improvement methodology that could be applied by healthcare sectors to reduce medication errors, increase patient safety and reduce operational costs.[19] Our research confirms the problems found with the administration of medication with infusion pumps found by other authors[4,5] who focused more on device safety whereas our focus was broader and less specific. Our initial initiatives were based on feedback and training. With the Lean approach, we introduced interventions similar to those found in the literature such as described by Schnock et al.[6]

Limitations

Lean interventions, although embraced by whole organizations, show their effect close to where the work is done. It must be noted that the interventions leading to our results were relatively simple. This might be caused by the use of Lean. When complex interventions are needed, there is a possibility that Lean is not the appropriate method, particularly when more departments or employees from different teams are involved. This work was done in a single ICU in a teaching hospital and it might well be that this limits the generalizability. This study uses audits as a basis for the evaluation of the Lean method with a possible problem in the precision of the measurements. Since the audits were not performed by the same person every time, the errors to be measured could have been interpreted differently by the various auditors. Although every possible error was well defined and instruction to the auditors, limited to three persons, was performed, we think that this effect on the level of confidence is small, but not entirely negligible. Another possible problem hampering the correct interpretation is the fact that audits were performed by intensive care nurses. They judged their peers. One could assume that this would result in a forgiving attitude towards the peers and thus that more errors were made than reported. By asking different auditors, we were hoping to attenuate the above-described possible bias. We did not measure the effect on the outcome of patients.

We did not collect data on the kind of medication that was in the syringes. It would have been interesting to see (if possible with sample size) whether there is an effect of the kind of medication on the number of errors. For instance, wrong medication in the case of antibiotics could be considered more serious than wrong rate with vasopressors.

Although one might presume that reduction in errors in the use of IV medication could lead to a reduction in morbidity and mortality, we did not investigate this possible important effect. Most medication errors in the ICU occur with the administration of (intravenous) medication,[20] which is also the focus of this study. Prescription errors were not included. One of the weaknesses of our interventions is that none of them was specifically aimed at the underlying cause 'dissonant behaviour'. It could be argued that the intervention of changing syringes together could influence culture by peer pressure. Another important limitation is that this work is done and presented in the emerging field of improvement science. This means that the body of literature with which to relate is limited. A recent study by Gonzalez Aleu and Van Aken[21] into publication patterns in this emerging field shows that while using a wide search strategy only 305 publications could be identified.

Conclusion and relevance

This study shows that a Lean approach is successful in reducing the number of errors with the administration of medication with syringe infusion pumps in the ICU. Although the reduction in the number of errors might not have a direct impact on patient outcome, it is imperative that higher quality healthcare can be delivered.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethical approval

According to the policy activities that constitute research at the Academic Medical Centre, Amsterdam, The Netherlands, this work met criteria for operational improvement activities exempt from ethics review.

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ORCID iD

Dave A Dongelmans https://orcid.org/0000-0001-8477-6671

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