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The learning curve for ultrasound-guided peripheral intravenous cannulation in adults: a multicenter study

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Abstract

Aims: To lower the threshold for applying ultrasound (US) guidance during peripheral intravenous cannulation, nurses need to be trained and gain experience in using this technique. The primary outcome was to quantify the number of procedures novices require to perform before competency in US-guided peripheral intravenous cannulation was achieved. **Materials and methods:** A multicenter prospective observational study, divided into two phases after a theoretical training session: a hands-on training session and a supervised life-case training session. The number of US-guided peripheral intravenous cannulations a participant needed to perform in the life-case setting to become competent was the outcome of interest. Cusum analysis was used to determine the learning curve of each individual participant. **Results:** Forty-nine practitioners participated and performed 1855 procedures. First attempt cannulation success was 73% during the first procedure, but increased to 98% on the fortieth attempt ($p<0.001$). The overall first attempt success rate during this study was 93%. The cusum learning curve for each practitioner showed that a mean number of 34 procedures was required to achieve competency. Time needed to perform a procedure successfully decreased when more experience was achieved by the practitioner, from 14±3 minutes on first procedure to 3±1 minutes during the fortieth procedure ($p<0.001$). **Conclusions:** Competency in US-guided peripheral intravenous cannulation can be gained after following a fixed educational curriculum, resulting in an increased first attempt cannulation success as the number of performed procedures increased.

Keywords: catheterization, peripheral; vascular access devices; ultrasound guidance; difficult vascular access; learning curve

Introduction

Obtaining intravenous access is a basic and vital part of modern healthcare to provide for fluid resuscitation, administration of medications and blood products or for diagnostic imaging studies. Peripheral intravenous cannulation has an estimated prevalence up to 85% in hospitalized patients [1,2]. The general hospitalized population is increasing in age with multiple comorbidities, resulting more often in difficult vascular access. In many countries, nurses are primarily responsible for the insertion and maintenance of peripheral intravenous catheters [3].

A previous study reported a success rate of 81% on the first attempt of peripheral intravenous cannulation with the traditional landmark technique of visualizing and palpating the extremity to identify the target vein, as performed by trained and experienced practitioners [4]. This means that nearly one out of five patients suffers from a failed first attempt [4]. Despite its routine nature, intravenous access cannot be established successfully on

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the first attempt in every patient. In these situations, advanced techniques to obtain vascular access are required, including ultrasound-guided peripheral intravenous cannulation [5–7].

Improvements in technology facilitated the growth of point-of-care ultrasonography (POCUS) devices that are more compact, with good image quality and less expensive [8]. Ultrasound-guided peripheral intravenous cannulation is recommended by recent guidelines to facilitate placement of devices in veins that are difficult to palpate or visualize [9]. To lower the threshold for applying ultrasound (US) guidance during peripheral intravenous cannulation, different healthcare providers need to be trained and gain experience in using this technique, including nurses. Training and practice will subsequently improve US use and increase success [10]. Education and training of nurses in US-guided peripheral intravenous cannulation is becoming increasingly common and is a key in the management of the difficult-access patient [11,12]. Competency on US-guided peripheral intravenous cannulation can be achieved after following a brief training in a fixed curriculum consisting of a theoretical training session, followed by a hands-on session in a simulated environment and finally a supervised life-case training [10].

There is no unambiguous definition of competency regarding the procedure of US-guided peripheral intravenous cannulation [13–15]. The primary outcome of the current study was to quantify the number of procedures novices need to perform in a life-case supervised environment before competency in US-guided peripheral intravenous cannulation was achieved. Competency was established with cusum analysis. In fact, optimal performance of US-guided cannulation has to be completed in the least amount of time with the highest success rate on the first attempt of cannulation.

Materials and methods

Design and setting

This study was conducted as a multicenter prospective observational study. The study was performed in the preoperative holding area of the theatre complex at the Catharina Hospital (Eindhoven, The Netherlands), on the oncology ward of the Elisabeth-TweeSteden Hospital (Tilburg, The Netherlands) and on the radiology department of the Bravis Hospital (Roosendaal, The Netherlands). Data collection was performed between August 2020 and April 2021. Ethical approval for this study (reference number W20.029) was provided by the Medical Ethics Committee United (MEC-U, Nieuwegein, The Netherlands). Written informed consent was obtained from all participants and patients prior to the start of the training and the procedure of peripheral intravenous cannulation.

Participants

The population (participants) in this study consisted of nurse anesthetists, PACU nurses, oncology nurses and radiographers. Participants were asked to take part on a voluntary basis as they were novices in US-guided peripheral intravenous cannulation. Participants who were not competent and qualified in peripheral intravenous cannulation with the traditional landmark approach, those with prior experience in US-guided peripheral intravenous cannulation, those in training, as well as participants with an employment less than three days a week were excluded. No sample size calculation was performed, because this was an observational study.

Educational program

Before performing US-guided peripheral intravenous cannulation on patients, participants received a brief training in a fixed curriculum, according to previous research [10]. Educational programs were identical and performed by the same educators throughout the included departments to guarantee consistency. Educators were researchers involved in this study, who are experienced in US-guided peripheral intravenous cannulation. The entire training was completed in six consecutive weeks. During the first two weeks, theoretical and hands-on training was completed. The supervised life-case training was completed in the following four weeks.

Participants first completed a pre-test including 40 questions to test the foreknowledge about US-guided peripheral intravenous cannulation. Thereafter, participants studied a reader with background and theoretical information and followed a one-hour face-to-face training including lectures to support the transfer of knowledge [10,16]. Finally, participants closed the theoretical training session by completing a post-test of 40 questions. Scores on both the pre- and post-test were calculated and represented on an eleven-point numeric rating scale (NRS), based on the number of questions answered correctly ("0" indicating no single question answered correctly, "10" indicating all questions answered correctly).

The theoretical training was followed by a hands-on training, requiring participants to gain and show competency before acting on life cases [10]. A hands-on training session in a simulation setting creates a situation in which practitioners can familiarize themselves with the US machine and equipment. Furthermore, it enables participants to focus on basic US acquisition and creating still images, as well as becoming aware of the upper extremity anatomy. During the hands-on training, ten participants were included in each session at most. Identifi-

cation of the anatomy of the upper extremity by tracing veins on a life model without cannulating allows participants to appreciate the vein characteristics and gain eye-hand coordination with probe manipulation [10]. Each practitioner had 30 minutes to practice tracing veins on a life model (classmate) without cannulating it. Both short-axis and long-axis viewing techniques were practiced. No data collection was performed during this period. After this, practitioners were able to cannulate one of the phantoms (Branched 4-vessel Ultrasound Training Block Model, Blue Phantom, Redmund, WA, USA and PunctR, CareVisionair, Eindhoven, The Netherlands) and collected data. Participants performed at least 15 US-guided cannulations on the phantom in a maximum of 60 minutes. Both short-axis and long-axis viewing techniques were used, based on trainees' preferences. Data regarding these 15 cannulations (successful first attempt, number of attempts needed to perform a successful procedure, time needed to perform cannulation successfully, used US-guided technique) were registered in the participants logbook and used for analyses.

After completing the hands-on training, participants moved to the life-case setting. Participants gained experience and routine in cannulating veins on the upper extremity with US-guided technique in human subjects (patients). Both inpatients and outpatients with an indication for intravenous access were recruited from the different units of the hospitals. All patients over 18 years of age were asked for participation regardless of their ASA (American Society of Anesthesiologists) physical status, demographics and medical history. Besides age, there were no exclusion criteria, resulting in the most real reflection of the actual population of patients. Focus of the participants should be on keeping the needle tip in the US field while navigating to the vein, perfecting probe control, treading the needle under US guidance and attempting cannulation of both smaller and deeper veins. Participants were required to perform at least 40 US-guided procedures on patients, with both short-axis and long-axis viewing technique. Throughout this study phase, direct supervision of an experienced clinician was available on the research site for the first ten procedures. The supervisor provided feedback to improve techniques of the practitioner in an interactive fashion and checked whether or not the attempt of US-guided peripheral intravenous cannulation was performed according to hospital protocols and international guidelines [17]. For the following procedures, the supervisor was available on call to assist for trouble-shooting or support the practitioner. Data regarding these 40 cannulations (successful first attempt, number of attempts needed to perform a successful procedure, time needed to perform cannulation successfully, used US-guided technique, patient-related data) were registered in the participants logbook and used for analyses. Peripheral intravenous cannulation was carried out according to current hospital protocols, based on international standards for intravenous cannulation [9,18–20].

Ultrasound

The US device used in this study was the Philips Lumify® L12-4 transducer (Philips Medical, Eindhoven, The Netherlands). The US-guided technique for inserting a peripheral intravenous catheter was performed by a one-person, short-axis or long-axis viewing technique.

Study outcomes

The outcome of interest was the number of US-guided peripheral intravenous cannulations a participant needed to perform successfully in the life-case setting to achieve competency, based on a cusum analysis. Intravenous cannulation was considered successful if the practitioner was able to inject a saline flush without signs of infiltration. An attempt was determined as a percutaneous needle puncture, regardless of the amount of subcutaneous exploration from the single puncture site. After a failed attempt, a new attempt was executed by firstly localizing a vein, followed by a new percutaneous puncture. All attempts needed to achieve successful intravenous access in one patient were described as a procedure. Secondary outcomes of the current study were the first attempt success rate of US-guided cannulation in the life-case setting and time needed to obtain successful intravenous access. Time needed for the procedure of peripheral intravenous cannulation was registered in minutes, from applying the tourniquet until the catheter was inserted successfully, including the time necessary for preparations (e.g. selection of devices and supply or putting on gloves).

Statistical analyses

The Kolmogorov-Smirnov test assessed the normality assumption for continuous variables. Comparison of variables was performed using Chi-squared testing for discrete variables, and Kruskal Wallis testing or one-way ANOVA testing for continuous variables, as appropriate. The relation between the success ratio and patient-related, procedure-related, and practitioner-related data was detected with logistic regression analysis. Participants were assigned a binary score for each attempt (0=failed attempt, 1=successful attempt). Learning curves were constructed for each individual participant by calculating cumulative sum (cusum) statistics using the following parameters: probability of type I error (α)=0.05, probability of type II error (β)=0.2, acceptable failure rate (p1)=10%, and unacceptable failure rate (p0)=20% [21]. These four variables determined the decision limits of acceptable (h0) and unacceptable performance (h1) [21,22].

After each procedure, the cusum sequentially tests the null hypothesis that performance was inadequate and cannulation unsuccessful [23]. The cusum chart starts at 0. For each successive success, *s* is subtracted from the cusum score. For each failure, (1–*s*) is added to the score [21]. In this, *s* is calculated to be 0.1452. Graphically, the cusum score is represented on the y-axis and number of procedures on the x-axis [23]. The intervention lines given using these parameters were a score of less than –1.92 signaling no significant difference between the acceptable failure rate and the actual failure rate (taken to imply procedural competence) and a score of +3.42 signaling a significant difference between the acceptable failure rate and the actual failure rate (taken to imply incompetence) [24]. Differences between the included centers were not cannulated and not of interest in this study. An Excel electronic spreadsheet (Microsoft, Bellevue, Washington, USA) was used to construct cusum curves. All other analyses were performed with SPSS (version 27.0, SPSS Inc., Chicago, Illinois, USA). Throughout the study, a p value less than 0.05 was denoted as statistically significant.

Results

In total, 49 practitioners participated in the current study. Of the included sample, 19 (39%) work as a nurse anesthetist, 9 (18%) as a PACU nurse, 11 (22%) as a general nurse on the oncology ward and 10 (21%) as a radiographer on the radiology department. The mean age of the included sample was 34±13 years and 15 (31%) were of male sex. None of the participants had prior experience with US upon peripheral intravenous cannulation. All included practitioners completed the pre-test, with a mean test score of 6.4±0.8. The post-test was completed by 42 (86%) practitioners, with a mean score of 8.2±0.6 ($p<0.001$, $t=11.97$).

All practitioners participated in the hands-on training and performed 15 procedures on the phantoms (Table I). First attempt cannulation success during this training session was 40% for the first performed procedure but increased to 97% for the fifteenth procedure ($p<0.001$, $\chi^2=36,89$). Time needed for successful cannulation during the hands-on training session decreased from 12.3±4.5 minutes upon the first procedure to 3.6±1.7 minutes for the fifteenth procedure ($p<0.001$, $t=12.66$).

In the life-case training session all 49 participants were included. Of those, 40 (82%) completed the session with 40 procedures. A total of 2066 punctures were performed. The first attempt success rate during this session was 93%. The success rate on the first procedure was 73%. During the first ten supervised procures, a first attempt cannulation success of 81% was recorded ($p=0.122$, $\chi^2=2.40$). First attempt cannulation success on the fortieth attempt was 98%, which was significantly higher when compared to the first attempt ($p<0.001$, $\chi^2=80.76$). First attempt success rates increased during the following procedures (Table II).

The cusum learning curve for each practitioner in the total cohort of practitioners is shown in figure 1. In total, 38 (78%) participants gained competency within 40 procedures, resulting in a lower failure rate per procedure

Table I. Outcome of the procedures during the hands-on training session on phantoms

	Overall N=49	Group 1 N=19	Group 2 N=9	Group 3 N=11	Group 4 N=10
Success rate on the first procedure	40%	48%	26%	41%	37%
Success rate on the fifteenth procedure	97%	98%	95%	96%	98%
Time on the first procedure (min)	12.3±4.5	14.2±5.5	11.8±4.9	11.5±4.3	12.3±3.4
Time on the fifteenth procedure (min)	3.6±1.7	3.7±1.6	4.0±1.9	3.5±1.8	3.3±1.6

Group 1=nurse anesthetists, group 2=PACU nurses, group 3=oncology nurses, group 4=radiographers.

Table II. Cannulation success on the first attempt during the life-case session

	Overall N=49	Group 1 N=19	Group 2 N=9	Group 3 N=11	Group 4 N=10
Success rate on all procedures	93	93	93	92	92
Success rate on procedure 1–10	81	81	82	83	81
Success rate on procedure 11–20	92	92	95	93	92
Success rate on procedure 21–30	96	97	96	96	97
Success rate on procedure 31–40	98	98	98	98	98

Data are expressed in percent (%). Group 1=nurse anesthetists, group 2=PACU nurses, group 3=oncology nurses, group 4=radiographers.

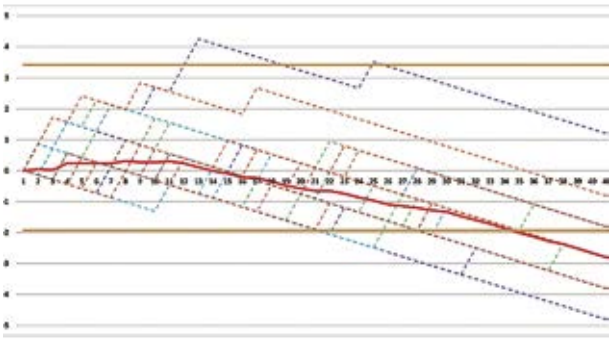

Fig 1. Cusum learning curve for each practitioner to achieve competency in ultrasound-guided peripheral intravenous cannulation in the life-case session. Red line: mean cusum score of the performed procedures. Lower yellow line: H_0 lower limit. Upper yellow line: H_1 upper limit. Dashed lines: the cusum learning curve of each individual nurse anesthetist (green), PACU nurse (purple), oncology nurse (blue) and radiographer (orange).

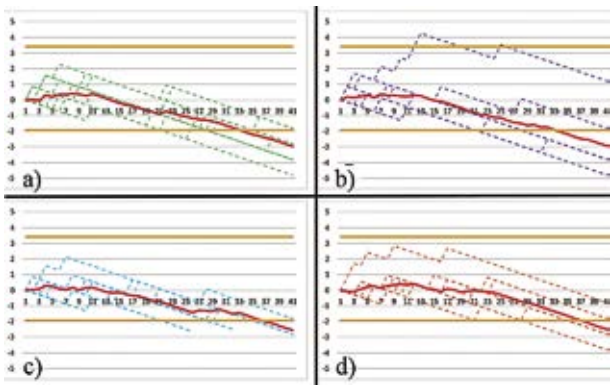

Fig 2. Cusum learning curve for each practitioner to achieve competency in ultrasound-guided peripheral intravenous cannulation in the life-case session as represented for each cohort separately. Red line: mean cusum score of the performed procedures. Lower yellow line: H_0 lower limit. Upper yellow line: H_1 upper limit. Dashed lines: the cusum learning curve of each individual participant, with A=nurse anesthetists, B=PACU nurses, C=oncology nurses, D=radiographers.

than the acceptable failure rate. Of 11 (22%) participants, no statistically inference can be made and competency was not achieved. A mean number of 34 procedure was needed to achieve competency. A minimum of 21 procedures was needed to gain competency. Cusum learning curves for the different cohorts are represented in figure 2.

Time needed to perform a procedure successfully decreased when more experience was achieved by the practitioner (fig 3). Whereas a mean time of 14±3 minutes was needed to obtain successful peripheral vascular access with US on first procedure in the life-case training session, were 3±1 minutes needed during the fortieth attempt, as represented in Table III ($p<0.001$, $t=12.09$).

According to the A-DIVA (Adult Difficult IntraVenous Access) scale, 1261 (68%) had a low risk profile for a difficult intravenous access, whereas 427 (23%) and 167 (9%) patients had a moderate and high risk profile on that scale. Success rates differed between risk groups ($p=0.373$, $\chi^2=0.793$, df=2), as shown in Table IV. Nonetheless, a patients individual A-DIVA risk profile did not affect the learning curve of the practitioners $p=0.530$, $\rho=-0.170$). When compared to the low risk group, increased procedure times were measured in the moderate risk group ($p<0.01$, $t=11,91$) and high risk group ($p<0.01$, $t=7,75$).

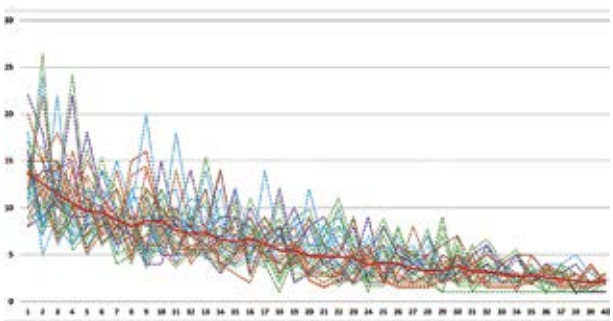

Fig 3. Time needed to obtain peripheral intravenous access with the ultrasound-guided technique in the life-case session. Red line: mean time needed to successful cannulation per procedure. Dashed lines: time to successful cannulation of each individual nurse anesthetist (green), PACU nurse (purple), oncology nurse (blue) and radiographer (orange).

Table III. Time to successful cannulation during the life-case session

	Overall N=49	**Group 1 N=19**	**Group 2 N=9**	**Group 3 N=11**	**Group 4 N=10**
Time to success on all procedures	6±4	6±4	6±4	7±4	6±4
Time to success on procedure 1–10	10±4	10±4	11±4	10±4	11±4
Time to success on procedure 11–20	6±2	6±2	7±2	7±3	6±2
Time to success on procedure 21–30	4±2	4±2	4±2	5±2	4±2
Time to success on procedure 31–40	3±1	2±1	3±1	3±1	3±1

Time is expressed in minutes. Group 1=nurse anesthetists, group 2=PACU nurses, group 3=oncology nurses, group 4=radiogra-phers.

Table IV. Success rates according to a patient's risk profile on the A-DIVA scale

A-DIVA risk profile	Success rate (%)	Time (min)
Low risk (N=1261)	94	6±3
Moderate risk (N=427)	90	8±3
High risk (N=167)	94	8±4

Discussion

In the current study, nurses followed a fixed curriculum in US-guided peripheral intravenous cannulation. In general, competency was achieved after performing 34 procedures in a life-case training session under direct supervision. Of the included sample of participants, 39 (80%) gained competency within 34 procedures. Furthermore, it is expected that all participants would have gained competency if they were able to perform enough procedures, according to the downward trend in the analysis. Subsequently, time to successful US-guided peripheral intravenous cannulation decreased as the number of performed procedures increased.

Edwards et al stated in a previous paper that the biggest question for determining competency was how many supervised successful procedures are necessary before a practitioner could perform the procedure independently [25]. This was underlined in the publication by Van Loon et al, representing a wide range in the number of procedures that needed to be performed under direct supervision [10]. In the current study, participants performed ten US-guided cannulations under direct supervision. The number of ten supervised procedures was based on previous publications [10,26-28]. Nonetheless, the current results show a remarkable increase of first attempt cannulation success after ten supervised procedures. Except for practical experience in the procedure of US-guided peripheral intravenous cannulation, the value of theoretical knowledge should not be underestimated [29]. It seems trivial that first attempt cannulation success would be improved if practitioners with greater procedural experience and an increased perception of the likelihood of success performs the cannulation [30].

Time needed to successful US-guided cannulation is affected by the number of failed attempts, which can simply be explained by the fact that each new attempt had to be executed by localizing another suitable vein [4]. But more importantly, time to successful cannulation is determined by the level of experience of the depending practitioner. This logically explains the reason more time is required to obtain successful peripheral intravenous access in the first ten procedures, when compared to time needed in further attempts. Hand-eye coordination, described as holding the probe and watching the US monitor, is denoted as the most difficult aspect of utilizing US-guided cannulation [31]. Experience in hand-eye coordination is necessary to cannulate the vein under real-time US guidance [32,33].

Several studies concluded that the use of US during peripheral intravenous cannulation is recommended in those patients at risk for a difficult intravenous access or failed cannulation [6,7,34]. This recommendation is in agreement with the latest guidelines on peripheral vascular access [17]. A difficult intravenous access can be identified prospectively in the individual patient with the A-DIVA scale [4]. First attempt cannulation success was lower in patients with a moderate risk profile according to the A-DIVA scale (63%) and even lower in patients at high risk (6%). The current study demonstrates that first attempt success rates are notably higher after the use of US, with success rates of 90% and 94% in the moderate and high risk groups respectively. Besides the increased success rates, significantly more time was needed to obtain successful peripheral intravenous access in patients at moderate and high risk, although the clinical relevance in comparison to first attempt cannulation success is questionable.

Insertion of peripheral intravenous catheters is a clinical skill that is part of nurses' remit. Training of broad range of nurses in US-guided peripheral intravenous cannulation will increase first attempt cannulation success in the individual patient., Additionally, competent nurses in this procedure will result in an efficient and effective use of technology, decreasing the medical workload by the simple fact that there would be less need to consult other professionals, and the procedure of peripheral intravenous cannulation, in general, would be optimized [35].

In our study there are some limitations. The current study consisted of a small cohort of nurses. Despite the fact that the practitioners were taken from different hospitals and were employed in different departments, a smaller sample size possibly introduced a poor reliability of research findings and negatively affected the likelihood that a nominally statistically significant finding actually reflected a true effect [36]. In addition, these participants were included based on their intrinsic motivation, leading to a potential bias regarding the level of willingness. Furthermore, participants in the current study were highly experienced in peripheral intravenous cannulation with the traditional landmark approach. Therefore, it is not directly possible to translate the results of this study to novice healthcare providers without any experience or knowledge in obtaining vascular access. Another issue that could have possibly influenced the study results is the presence of the Hawthorne effect, because practition-

ers knew they were merely participating in an experiment [37]. This prevalent observer effect can cause behavioral changes to participants in clinical studies and confound the interpretation of experimental manipulations [37,38]. To continue, data were self-reported in a logbook, which is subject to bias. A blinded observer would have improved the study design. Finally, the method of US needle guidance was not standardized given the difference in training and outcomes. Both the short-axis (out-of-plane) and long-axis (in-plane) viewing technique were used throughout the study. The gauge of the inserted intravenous catheter was also not standardized, which may possibly influence the results of the study.

In **conclusion**, competency in US-guided peripheral intravenous cannulation can be gained after following a fixed educational curriculum. The combination of theory-based didactic training, followed by a hands-on training session and a supervised training session in a life-case session, resulted in a steep learning curve. In general, nurses were competent in the procedure after performing 34 procedures. First attempt cannulation success increased as the number of performed procedures increased, while the time required to obtain successful vascular access decreased. Thus, the training of nurses in US-guided peripheral intravenous cannulation will result in beneficial outcomes for daily clinical practice.

Conflict of interest: none

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