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Improving compliance with isolation measures in the operating room: a prospective simulation study comparing the effectiveness and costs of simulation-based training vs video-based training

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SUMMARY

Background: Different isolation measures are required according to the routes of transmission of pathogens. Few studies have compared different forms of hygiene training in terms of efficiency and/or improvement of perception towards hygiene measures. This study aimed to evaluate the benefits of different forms of isolation training in the operating room, and their respective effects on the perception of hygiene measures by comparing simulation training with video-based training.

Methods: This multi-centre, prospective, randomized, controlled trial compared hygiene knowledge, psychological safety and perception of training among healthcare workers after in-centre simulation training and conventional video-based training.

Results: Neither type of training led to a significant improvement in knowledge or perceived psychological safety ($F=0.235$, $P=0.629$, $\eta^2=0.003$). Participants in the simulation group reported higher levels of willingness to speak up in the depicted scenario compared with participants who received video-based training. Participants perceived the simulation-based training significantly more positively than the video-based training.

Conclusion: Clear definition of the goals of training based on the pre-existing level of knowledge of the participants is crucial. For future studies, it would be interesting to investigate the long-term effect and continuing benefits concerning the implementation of hygiene regulations after different types of training.

Background

Multi-drug-resistant organisms (MDROs) have spread alarmingly across the globe [1]. Solid application of hygiene and

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isolation measures, such as droplet isolation, contact isolation and airborne isolation, represents the fortress against the increasing incidence of infections with MDROs. However, their execution during clinical routine is inconsistent, and in-hospital adherence to isolation measures is limited [2—5]. Over one-third of healthcare workers (HCWs) make several mistakes when handling their personal protective equipment (PPE) while treating patients under isolation measures (e.g. contact isolation with protective gown and gloves) [6—8]. This is a significant, complex and puzzling patient safety problem in which individual (e.g. limited knowledge, limited motivation), team (e.g. hygiene culture, openness to talk about hygiene problems) and organizational (e.g. policies) factors interact [3,9—13]. For example, minor rule violations are more likely if adverse events happen with a time delay, which is often the case with poor adherence to hygiene measures, meaning that they are not seen by the person who caused the damage. Over time, these violations are perceived as unproblematic, are copied by younger staff and are finally accepted as normal [14]. Moreover, HCWs feel uncomfortable when having to speak up about hygiene concerns [12]. As a consequence, educating HCWs to increase compliance with hygiene measures is a complex endeavour [15].

While exposure to isolation training has been associated with higher levels of compliance, few studies have compared different forms of isolation training [3,15]. Simulation-based training has been found to be effective, but it is expensive [16—18]. Regular isolation training should be effective, efficient and accepted by HCWs. Studies comparing the effectiveness of simulation-based isolation training with less resource-intense types of training are lacking.

Isolation training measures that are effective and feasible are needed. The aim of this study was to compare two different isolation training methods: simulation-based training and video-based training. Their impact on four outcomes was evaluated: knowledge of hospital isolation rules; psychological safety; reactions; and costs. Psychological safety (i.e. perception of the consequences of taking an interpersonal risk at work, such as by speaking up with isolation concerns) was included because of the strong evidence of its importance for learning and teamwork, particularly in health care [19,20]. When training HCWs in skills such as performing isolation measures, evaluation of the psychological safety of the participants and teamwork is important to ensure implementation in the daily work routine [17]. This study investigated the following four hypotheses.

- Hypothesis 1: Participants report higher levels of knowledge about hygiene regulations after simulation training compared with video-based training.
- Hypothesis 2: Participants report higher levels of psychological safety after simulation training compared with video-based training.
- Hypothesis 3: Participants perceive simulation training more positively than video-based training.
- Hypothesis 4: Video-based training is more cost-effective than simulation training.

Methods

Ethics

The Cantonal Ethics Committee of Zurich, Switzerland reviewed the study protocol of the in-situ simulation study and issued a declaration of no objection (Ethics Committee No. 2020-00059). All participants gave oral consent to participate in the study.

Study design

This multi-centre, prospective, randomized, controlled trial compared hygiene knowledge, psychological safety and perception of training among HCWs after in-centre simulation training and conventional video-based training. Furthermore, a cost comparison between the two different types of training was undertaken. The simulation training was conducted in two different simulation centres [a large university hospital (Hospital A) and a cantonal hospital (Hospital B) in Switzerland] between November 2020 and October 2021, and the video-based training was performed solely at Hospital A in November 2021.

Participants and inclusion/exclusion criteria

The sample consisted of HCWs working in anaesthesiology departments. Participants included physicians (registrars and consultants) and anaesthesiologic nurses. The inclusion criterion was completion of education that enabled the HCW to intubate and manage anaesthesia. HCWs from other departments and anaesthesiologic senior attending physicians were excluded in order to create a psychologically safe environment for the younger residents and nurses. The criteria were the same for both types of training. Only HCWs who had not participated in the simulation training were included in the video group. The participants were either given a day off for training or relieved from their work, and all were compensated with credits for mandatory clinical training. Participants were allocated to the different intervention groups at random.

Simulation-based training

The pre-training questionnaire was sent to the participants on the day before training. Simulation-based training took place in a fully equipped simulated operating room using a high-fidelity mannequin as a patient simulator. A standardized, predefined plot was used for briefing the participants, simulation guidance and debriefing, which is presented in the online supplementary material. Simulation training consisted of an introductory presentation, familiarization with the simulation mannequin and material, two simulation scenarios, and a 10-min instruction movie about the correct hygiene procedure for a patient with coronavirus disease 2019 (COVID-19) before the second scenario. As two different hospitals were involved in simulation training, the instruction movie of the respective hospital was used in each simulation centre. The movies were created by an attending anaesthesiologist according to a standard operating procedure, and there was no difference in content between the two hospitals. The hygiene rules in the

two hospitals were identical. Employees had to don protective clothing when entering the room. This clothing consisted of a protective gown and gloves for contact isolation; FFP2 mask and goggles for droplet isolation; and gown, gloves, FFP2 mask and goggles for combined isolation.

Each team consisted of three to six participants, including at least one nurse and one doctor. The cases for the scenarios were designed by a senior anaesthesiologist. Both scenarios depicted a patient in a standard situation, where hygiene measures were necessary due to infectious disease, with a non-routine emergency. Each scenario was limited to 15 min, followed by a 45—60-min debriefing. The focus of the debriefings was on compliance and difficulties with hygiene regulations, and communication within the team, including willingness to speak up and teamwork. If necessary, a video review was available for the sole purpose of the debriefing. There was no further usage of the videotapes. After the second debriefing, the participants completed the post-training questionnaire.

Video-based training

The video-based training consisted of a 20-min educational video in which a senior attending physician explained the hygiene regulations, the potential sources for transmission of infection, and the corresponding isolation measures. It presented certain standard operating procedures and encouraged the participants to revise them online. The instruction movie on intubating a patient with COVID-19 was not shown explicitly, but the theoretical background was covered. A resident anaesthesiologist introduced the study to the participants and showed them the above-described video without further explanation, discussion or debriefing. The participants completed the pre- and post-training questionnaires immediately before and after training.

Measures

Except for the cost calculations, all variables were measured through the questionnaires. The set-up of the questionnaires is depicted in Table I.

Psychological safety

Psychological safety was assessed using six items of the well-established psychological safety scale [21—23]: (a) 'Everyone on my team can address problems and difficult issues'; (b) 'No one deliberately undermines my efforts'; (c) 'If someone makes a mistake, it is held against him/her'; (d) 'Some people on the team are rejected for being different'; (e) 'Other team members value my skills and talents'; and (f) 'It is difficult to ask others for help'. Participants indicated their agreement with these items on a five-point Likert scale ranging from 1 ('strongly disagree') to 5 ('strongly agree'). Negatively formed items that were reverse-coded before evaluation were included in order to mitigate response set bias.

Case vignette

A case vignette was created to assess each participant's perception of hygiene neglect and their presumed behaviour [24,25]. It described a stressful situation in which a consultant physician disregarded hand hygiene whilst treating a contact-isolated patient and was linked with four items (Table IV).

Table I
Data collection and set-up of the questionnaires

	Centre	
Intervention	Hospital A	Hospital B
Simulation	x	x
Video	x	
Set-up of the questionnaires (equal for both interventions and locations)		
Measures	Pre-training questionnaire	Post-training questionnaire
Demographic information	x	
Psychological safety	x	x
Case vignette	x	x
Knowledge test of hygiene measures and infectiology alternating every other intervention day	x Group A: Questions 1—10 Group B: Questions 11—20	x Group A: Questions 11—20 Group B: Questions 1—10
Training evaluation		x
Training cost	x	x

Knowledge test of hygiene measures, isolation standards and infectiology

A resident and senior attending physician of the Department of Infectiology designed questions in collaboration with a senior anaesthesiologist. In total, there were 20 questions with four response options. Eighteen questions were designed as multiple true—false types, where four answer possibilities are given and each of them has to be marked separately. The partial scoring method (PS_{50}) was used to evaluate these questions [25,26]. In the other two questions, the participants were asked to mark the correct order of donning or doffing PPE. Refers to unexplained types of questiones, since a larger explanation would bring no further enlightment to the reader I suggest cancelling.

In order to study any improvement in knowledge from before to after training, the knowledge test on hygiene measures was divided into two groups (10 questions each); Questions 1—10 (Part A) were included in the pre-training questionnaire and Questions 11—20 (Part B) were included in the post-training questionnaire. All participants on a particular training day were given the same set of questions. However, the sets were changed to alternate days to rule out difficulty bias within the questions, so on alternate days, the participants would fill out Part B (Questions 11—20) in the pre-training questionnaire and Part A (Questions 1—10) in the post-training questionnaire.

Training evaluation

Participants evaluated the training and its future benefits for their daily work using six items based on the pre-existing

Table II
Characteristics of participants

	Simulation training		Video-based training	
	N	%	*N*	%
Participants				
Hospital A	42	77.8	31	100
Hospital B	12	22.2	0	0
Total	54	100	31	100
Profession				
Nurse	17	30.9	11	35.5
Doctor	37	67.3	20	64.5
Years of experience				
Median (IQR)	6	7	5	5
Duration of employment (years)				
Median (IQR)	1.5	4.8	1	3.84
Prior hygiene training within the last 12 months				
Yes	45	81.8	21	67.7
No	9	16.4	10	32.3
Type of prior hygiene training				
Presentation	36	65.5	14	45.2
Video	17	30.9	6	19.4
Simulation	14	25.5	4[a]	12.9

IQR, interquartile range.
[a] Some participants had formal simulation-based hygiene training. However, none of them took part in this study before.

evaluation forms of the simulation centre (Supplementary File S3) [27].

Cost analysis

The costs of the two types of training were compared by calculating the cost of each participant from the hospital's perspective. As the two simulation centres involved have different approaches, two separate cost calculations were performed, listed in detail in the online supplementary material.

The costs for Hospital A were calculated using the hourly wage of the participants and the instructors during training. A training unit in the simulation centre lasted for 4 h with two instructors present, whereas a training unit based on video-based education lasted for 1 h with one instructor present. The amount corresponded to 45 Swiss Francs (SFR) rounded for registrars and nurses, and 65 SFR for consultants. The unit costs were obtained from the cantonal wage scale, assuming a 50-h working week with an average of 21 working days per month.

In the simulation centre at Hospital B, a standard cost of 1800 SFR was applied for a training unit lasting for 4 h and including four participants and two instructors. The one-time cost of creating the video and simulation scenarios was excluded.

Statistical analysis

Descriptive statistics were generated for all data. Demographic variables have been described as counts and percentages for metric variables, and continuous variables have been presented as medians and interquartile ranges. Prior hygiene training was dichotomized into two groups: any prior training and no prior training. If a participant reported zero years of experience, this was converted into a positive number, indicating at least 2 weeks of experience or 0.04 years.

A correlation coefficient was computed to assess the linear relationship between the different variables (see online supplementary material).

All scale items were assessed using a five-point Likert scale (1, strongly disagree; 5, strongly agree), and negatively formed items were reverse-coded for evaluation. The reliability of the explored scales was measured with Cronbach's α, and $\alpha \geq 0.60$ was considered to indicate good internal consistency [28].

Exploratory data analysis was conducted for all data. The results have been described as mean and standard deviation (SD) for normally distributed date, and median and interquartile range for non-normally distributed data. For normally distributed data and measurements before and after training, mixed analysis of variance was used to test for improvement over time and differences between the intervention groups. To analyse which type of training led to a greater increase in knowledge, the interaction of the two groups over time was examined using the within-subject effect test. A different increase in score over time between the two groups would imply that one form of training has a greater impact on knowledge. The Levene test was used to ensure homogeneity of the error variances. For data that followed a normal distribution but were only collected once (e.g. training evaluation), two independent samples *t*-test was used to check for significance. Mann–Whitney *U*-test was used to test for differences in non-normally distributed data between the groups.

Table III
Mean, standard deviation and mixed analysis of variance results

	Mean (SD)			Time effect (RM)		Group effect (IM)		Interaction group x time	
	Simulation (*N*=54)	Video (*N*=31)	*P*-value	F	η^2	F	η^2	F	η^2
Knowledge of hygiene regulations				0.528	0.006	5.076[a]	0.058	4.049	0.024
Pre-training questionnaire	5.51 (1.59)	5.76 (1.48)	0.479						
Post-training questionnaire	5.35 (1.59)	6.24 (1.15)	0.008						
Psychological safety				0.199	0.002	3.058	0.036	0.235	0.003
Pre-training questionnaire	3.69 (0.48)	3.53 (0.55)	0.508						
Post-training questionnaire	3.74 (0.55)	3.52 (0.60)	0.777						
Training evaluation									
Post-training questionnaire	5.15 (0.65)	3.67 (1.04)	<0.001						

RM, repeated measure; IM, independent measure; η^2, partial eta squared; SD, standard deviation.
[a] $P<0.05$.

For all analyses, $P<0.05$ was considered to indicate significance (two-tailed). Item difficulty analysis was used to check for comparability between the two different knowledge tests of hygiene measures.

All statistical analyses were performed using SPSS Version 27 (IBM Corp., Armonk, NY, USA).

Results

Questionnaires were completed in full and were identifiable for direct comparison between the pre- and post-training questionnaires by 77% (85/111) of participants. The simulation and video groups had nearly equal proportions of participants by profession, years of experience and duration of employment (Table II). Correlations between the different items are depicted in the online supplementary material.

Type of training and knowledge of hygiene measures

Neither type of training led to a significant improvement in knowledge. Although participants in the video group [mean 6.24 (SD 1.15)] achieved higher scores than participants in the simulation group [mean 5.35 (SD 5.35)] after training ($P=0.008$), the interaction effect between the two groups over time was not significant ($F=4.049$, $P=0.157$) and the effect strength was low ($\eta^2=0.024$) (Table III). Therefore, the two types of training did not have a different impact on knowledge of hygiene measures. However, the between-group effect was significant ($F=5.076$, $P<0.05$), indicating that the video group achieved higher scores than the simulation group (Supplementary File S2). Mean item difficulty was 0.51 (SD 0.23) for Questions 1–10 and 0.62 (SD 0.22) for Questions 11–20.

Psychological safety

Neither type of training led to a significant improvement in perceived psychological safety ($F=0.235$, $P=0.629$, $\eta^2=0.003$). The rating of psychological safety tended to increase after training (Supplementary File S2). However, this finding was not significant and there was no significant between-group effect ($F=3.058$, $P=0.084$, $\eta^2=0.036$) (Table III).

Results for the case vignette are shown in Table IV. Participants in the simulation group reported higher levels of willingness to speak up in the depicted scenario compared with participants in the video group. However, the difference over time, which would imply a direct benefit of training, was not significant.

Training evaluation

Participants evaluated the simulation-based training significantly more positively than the video-based training [simulation 5.15 (SD 0.65); video 3.67 (SD 1.04); $t(43.7)=7.2$, $P<0.001$] (Supplementary File S3).

Type of training and costs

Following the above-mentioned calculations for costs, the cost per participant for a training unit in the simulation centre was, on average, 380.00 SRF (310.95 SFR in Hospital A, 450.00 SFR in Hospital B). A video-based training unit cost 61.30 SFR per participant. Therefore, a training unit in the simulation centre is 6.2 times more expensive than a video-based training unit. The exact calculations are listed in the online supplementary material.

Discussion

This study compared the different effects of simulation training and video-based training on knowledge about hygiene measures, the participant's perception of the training and its future implementation in daily work, and how they influence teamwork and willingness to speak up.

Knowledge of hygiene measures

Many different approaches have been taken to improve hygiene procedures among hospital staff, but to date there is

Table IV
Median and standard deviation for different items in the case vignette before and after training

'You are in the operating room for a stoma retraction and the patient is under contact isolation due to a positive swab with an ESBL-producing *Klebsiella* spp. The patient becomes increasingly tachycardic and you realize that the infusion is no longer running properly. The consultant physician sets up the IV line and injects it without putting on gloves or disinfecting his hands'	Before training		After training		Difference over time[b]	
	Simulation	Video	Simulation	Video	Simulation	Video
How realistic is this situation?	3.45 (1.32)	3.81 (0.98)	3.50 (1.34)	3.97 (0.84)	0.10	0.16
If nobody reacts, how dangerous do you think this situation is for the patient and the consultant?	3.41 (1.02)	3.27 (0.95)	3.17 (1.25)	3.13 (1.06)	- 0.16	-0.34
Would you point out the lack of hygiene measures to the consultant?	3.27 (1.40)	2.81 (1.28)	3.54 (1.34)[a]	2.94 (1.21)	0.40	0.13
Would you feel uncomfortable mentioning the lack of hygiene measures to the consultant?	3.22 (1.31)	3.10 (1.38)	2.81 (1.28)	2.58 (1.34)	-0.31	-0.52

ESBL, extended-spectrum beta-lactamase; IV, intravenous.
Mann–Whitney *U*-test was used to check for significant differences after training.
[a] $P<0.05$.
[b] Mann–Whitney *U*-test showed no significance.

little evidence of a superior form of training. It has been shown that a combined approach of traditional teaching methods with complementary practice increases adherence to hand hygiene [29]. Although some studies showed significant results favouring a specific type of training [30,31], these results are inconsistent [32] and have not been affirmed through a broader review [33]. This is consistent with the present findings, demonstrating that neither simulation training nor video-based training led to a significant improvement in knowledge of hygiene measures. Although participants in the video group scored more highly after training compared with participants in the simulation group, the improvement over time was not significant, indicating no change due to training. To interpret the higher scores in the video group, one should consider that the video-based training was given 1 year after the simulation training. During that year, when the COVID-19 pandemic spread worldwide, isolation measures were part of every HCW's daily routine. Hence, it is assumed that general knowledge was higher regardless of the type of training.

The recently published World Health Organization Framework global survey showed no overall improvement in hand hygiene from 2015 to 2019, with most healthcare facilities already having an intermediate or higher level of hand hygiene [32]. This emphasizes the difficulty of increasing knowledge among highly educated personnel. With an average score of 55—58% before the intervention, the level of knowledge among the participants in both groups of this study was already good. Therefore, it is believed that the key to reducing neglect of isolation measures and therefore reducing in-hospital transmission of pathogens is to improve adherence to hygiene protocols and implementation of existing knowledge in daily work.

Psychological safety

It is well established that, through practical application and inclusion of every individual, simulation training leads to improved essential skills, and higher clinical performance and competence [34—36]. Furthermore, simulation training has a positive impact on team learning and on encouraging communication, thereby having a beneficial effect on teamwork skills [36,37]. This supports the present finding that the participants perceived the simulation training more positively, and felt more confident implementing their skills after simulation training compared with video-based training. The significant correlation between psychological safety and willingness to speak up, as well as the enhanced speak-up behaviour demonstrated in the case vignette after simulation training compared with video-based training, further demonstrates the benefits of simulation training in non-technical skills.

Training costs

Several studies have analysed the cost-effectiveness of simulation training (e.g. instructors' and participants' worktime, training materials). However, true measurement of the costs, including the amount to purchase a simulation centre is difficult and most studies have presented incomplete costs [38—40]. The present study showed that simulation training was six times more expensive than video-based training. Considering the benefits of simulation training, calculating the actual effectiveness becomes nearly impossible. There seems to be an overall benefit of training units that engage the learner in mental processing, such as simulation training, compared with passive transfer of knowledge [38,40].

Limitations

Direct comparison of the test results on hygiene knowledge with other studies was not possible, as most studies use self-report questionnaires to test for adherence to hand hygiene and the necessary competencies, whereas the test used in the present study focused on specific hygiene regulation in the operating room.

The circumstances under which the participants of the two groups completed the questionnaires were different. As the simulation training was organized in advance, participants received the pre-training questionnaire the day before training and completed the post-training questionnaire at the end of a 4-h training session with a presumably low level of concentration.

In conclusion, this study aimed to find a type of training that combines theoretical knowledge and better adherence to hygiene measures. Although there was no significant improvement in knowledge or psychological safety over time with either simulation training or video-based training, simulation training was rated more highly, showing higher acceptance among the participants. Considering the items included in the evaluation, this may indicate a beneficial effect on the daily implementation of hygiene measures. Regarding the high levels of knowledge among the participants before training, changes in perception towards hygiene measures and positive effects on future adherence following simulation training may be more important than increased knowledge. As higher psychological safety correlates with increased willingness to speak up, this plays a vital role in ensuring the correct handling of PPE [41].

Clear definition of the goals of training according to the pre-existing level of knowledge of participants is crucial. If the aim of the training unit is a theoretical input, video-based training is more cost- and time-effective. However, if the level of knowledge among the participants is already high, as was the case in this study, and the goal is overall improvement in adherence to hygiene measures and strengthening teamwork behaviour, the findings strongly recommend full-scale simulation training. For future studies, it would be interesting to investigate the long-term effects and continuing benefits regarding the implementation of hygiene regulations after different types of training.

Conflict of interest statement
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Author contributions
Conception and design: LS, BG.
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Collection and assembly of data: LS, BK, HJ, BG.
Data analysis and interpretation: LS, MK, BG.
Manuscript writing: All authors.
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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jhin.2023.07.027.

References

[1] Bryan-Wilson J. No time to wait. Artforum Int 2016;54:113—4.
[2] World Health Organization. Global action plan on antimicrobial resistance. Geneva: WHO; 2016.
[3] Sax H, Perneger T, Hugonnet S, Herrault P, Chraïti M-N, Pittet D. Knowledge of standard and isolation precautions in a large teaching hospital. Infect Control Hosp Epidemiol 2005;26:298—304.
[4] El-Sokkary RH, Khater WS, El-Kholy A, Mohy Eldin S, Gad DM, Bahgat S, et al. Compliance of healthcare workers to the proper use of personal protective equipment during the first wave of COVID-19 pandemic. J Infect Publ Health 2021;14:1404—10.
[5] Krein SL, Mayer J, Harrod M, Weston LE, Gregory L, Petersen L, et al. Identification and characterization of failures in infectious agent transmission precaution practices in hospitals: a qualitative study. JAMA Intern Med 2018;178:1016—22.
[6] Okamoto K, Rhee Y, Schoeny M, Lolans K, Cheng J, Reddy S, et al. Impact of doffing errors on healthcare worker self-contamination when caring for patients on contact precautions. Infect Control Hosp Epidemiol 2019;40:559—65.
[7] Kwon JH, Burnham CD, Reske KA, Liang SY, Hink T, Wallace MA, et al. Assessment of healthcare worker protocol deviations and self-contamination during personal protective equipment donning and doffing. Infect Control Hosp Epidemiol 2017;38:1077—83.
[8] Osei-Bonsu K, Masroor N, Cooper K, Doern C, Jefferson KK, Major Y, et al. Alternative doffing strategies of personal protective equipment to prevent self-contamination in the health care setting. Am J Infect Control 2019;47:534—9.
[9] Beam EL, Gibbs SG, Hewlett AL, Iwen PC, Nuss SL, Smith PW. Method for investigating nursing behaviors related to isolation care. Am J Infect Control 2014;42:1152—6.
[10] Yanke E, Zellmer C, Van Hoof S, Moriarty H, Carayon P, Safdar N. Understanding the current state of infection prevention to prevent *Clostridium difficile* infection: a human factors and systems engineering approach. Am J Infect Control 2015;43:241—7.
[11] Kramer TS, Bunte K, Schröder C, Behnke M, Clausmeyer J, Reichardt C, et al. No increase in compliance before aseptic procedures in German hospitals. A longitudinal study with data from the national surveillance system over four years. J Hosp Infect 2020;106:71—5.
[12] Schwappach DLB, Gehring K. Silence that can be dangerous: a vignette study to assess healthcare professionals' likelihood of speaking up about safety concerns. PLoS One 2014;9:e104720.
[13] Staines A, Amherdt I, Lécureux E, Petignat C, Eggimann P, Schwab M, et al. Hand hygiene improvement and sustainability: assessing a breakthrough collaborative in Western Switzerland. Infect Control Hosp Epidemiol 2017;38:1420—7.
[14] Banja J. The normalization of deviance in healthcare delivery. Bus Horiz 2010;53:139.
[15] Allegranzi B, Gayet-Ageron A, Damani N, Bengaly L, McLaws M-L, Moro M-L, et al. Global implementation of WHO's multimodal strategy for improvement of hand hygiene: a quasi-experimental study. Lancet Infect Dis 2013;13:843—51.
[16] Carvalho E, Castro P, León E, Del Río A, Crespo F, Trigo L, et al. Multi-professional simulation and risk perception of health care workers caring for Ebola-infected patients. Nurs Crit Care 2019;24:256—62.
[17] Patterson MD, Geis GL, Falcone RA, LeMaster T, Wears RL. In situ simulation: detection of safety threats and teamwork training in a high risk emergency department. BMJ Qual Saf 2013;22:468.
[18] Fent G, Blythe J, Farooq O, Purva M. In situ simulation as a tool for patient safety: a systematic review identifying how it is used and its effectiveness. BMJ Simul Technol Enhanc Learn 2015;1:103—10.
[19] Edmondson AC, Bransby DP. Psychological safety comes of age: observed themes in an established literature. Ann Rev Organiz Psychol Organiz Behav 2023;10:55—78.
[20] Tucker AL, Edmondson AC. Why hospitals don't learn from failures: organizational and psychological dynamics that inhibit system change. Calif Manage Rev 2003;45:55—72.
[21] Edmondson A. Psychological safety and learning behavior in work teams. Adm Sci Q 1999;44:350—83.
[22] Baer M, Frese M. Innovation is not enough: climates for initiative and psychological safety, process innovations, and firm performance. J Organ Behav 2003;24:45—68.
[23] Martinez W, Lehmann LS, Thomas EJ, Etchegaray JM, Shelburne JT, Hickson GB, et al. Speaking up about traditional and professionalism-related patient safety threats: a national survey of interns and residents. BMJ Qual Saf 2017;26:869—80.
[24] Richard A, Pfeiffer Y, Schwappach DDL. Development and psychometric evaluation of the Speaking Up About Patient Safety Questionnaire. J Patient Saf 2021;17:e599—606.
[25] Lahner FM, Lörwald AC, Bauer D, Nouns ZM, Krebs R, Guttormsen S, et al. Multiple true—false items: a comparison of scoring algorithms. Adv Health Sci Educ Theory Pract 2018;23:455—63.
[26] Kanzow P, Schuelper N, Witt D, Wassmann T, Sennhenn-Kirchner S, Wiegand A, et al. Effect of different scoring approaches upon credit assignment when using multiple true—false items in dental undergraduate examinations. Eur J Dent Educ 2018;22:e669—78.
[27] Kolbe M, Weiss M, Grote G, Knauth A, Dambach M, Spahn DR, et al. TeamGAINS: a tool for structured debriefings for simulation-based team trainings. BMJ Qual Saf 2013;22:541—53.
[28] Terwee CB, Bot SD, de Boer MR, van der Windt DA, Knol DL, Dekker J, et al. Quality criteria were proposed for measurement properties of health status questionnaires. J Clin Epidemiol 2007;60:34—42.
[29] Martos-Cabrera MB, Mota-Romero E, Martos-García R, Gómez-Urquiza JL, Suleiman-Martos N, Albendín-García L, et al. Hand hygiene teaching strategies among nursing staff: a systematic review. Int J Environ Res Public Health 2019;16:3039.
[30] McGaghie WC, Issenberg SB, Cohen ER, Barsuk JH, Wayne DB. Does simulation-based medical education with deliberate practice yield better results than traditional clinical education? A meta-analytic comparative review of the evidence. Acad Med 2011;86:706—11.
[31] Burden AR, Torjman MC, Dy GE, Jaffe JD, Littman JJ, Nawar F, et al. Prevention of central venous catheter-related bloodstream infections: is it time to add simulation training to the prevention bundle? J Clin Anesth 2012;24:555—60.
[32] Jansson MM, Syrjälä HP, Ohtonen PP, Meriläinen MH, Kyngäs HA, Ala-Kokko TI. Simulation education as a single intervention does not improve hand hygiene practices: a randomized controlled follow-up study. Am J Infect Control 2016;44:625—30.
[33] Lydon S, Power M, McSharry J, Byrne M, Madden C, Squires JE, et al. Interventions to improve hand hygiene compliance in the ICU: a systematic review. Crit Care Med 2017;45:e1165—72.
[34] Kurosawa H, Ikeyama T, Achuff P, Perkel M, Watson C, Monachino A, et al. A randomized, controlled trial of in situ pediatric advanced life support recertification ('pediatric advanced life support reconstructed') compared with standard pediatric advanced life support recertification for ICU frontline providers. Crit Care Med 2014;42:610—8.
[35] Minai F, Shafiq F, Ul Haq MI. Value of real life (in situ) simulation training for tracheal intubation skills in medical undergraduates during short duration anesthesia rotation. J Anaesthesiol Clin Pharmacol 2014;30:484—7.
[36] Couto TB, Kerrey BT, Taylor RG, FitzGerald M, Geis GL. Teamwork skills in actual, in situ, and in-center pediatric emergencies:

performance levels across settings and perceptions of comparative educational impact. Simul Healthc 2015;10:76—84.
[37] Kurup V, Matei V, Ray J. Role of in-situ simulation for training in healthcare: opportunities and challenges. Curr Opin Anaesthesiol 2017;30:755—60.
[38] Bluestone J, Johnson P, Fullerton J, Carr C, Alderman J, BonTempo J. Effective in-service training design and delivery: evidence from an integrative literature review. Hum Resour Health 2013;11:51.
[39] Zendejas B, Wang AT, Brydges R, Hamstra SJ, Cook DA. Cost: the missing outcome in simulation-based medical education research: a systematic review. Surgery 2013;153:160—76.
[40] Woolfolk A. Educational psychology. Upper Saddle River, NJ: Pearson/Merrill/Prentice Hall; 2009.
[41] Konicki T, Miller E. Use of a simulation intervention to examine differences in nursing students' hand hygiene knowledge, beliefs, and behaviors. Nurse Educ Today 2016;45:96—101.