The use of Deliberate Practice in Simulation-Based Surgical Training for Open General and Subspeciality Surgery: A systematic review

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Keywords: Simulation, open surgery, simulation, deliberate practice

Funding – None

Ethical requirements – Review of literature, no ethics approvals required

Word count - 3392

Summary statement

Simulation-based surgical training (SBST) provides a risk-free environment for surgical skill development. Integrating Deliberate Practice (DP) into SBST may enhance training effectiveness. This systematic review examines the application of DP elements in SBST for open general and subspecialty surgery, and their effectiveness in improving surgical skills. It aimes to systematically synthesize the use of DP elements within SBST and evaluate effects on trainee performance. To preserve methodological comparability, this review focused on open procedures in general surgery and its subspecialties.

The search identified 22 studies for inclusion, predominantly from North America and Europe. Most studies incorporated feedback and allowed repetition but commonly lacked structured assessments of learner motivation and individualised task design. Studies generally reported improvements in surgical skills following DP-informed SBST; however, the correlation between the number of DP elements used and learning outcomes was inconsistent. Kirkpatrick levels 1 and 2 evaluations were most common. The results suggest that DP-informed SBST improves skill acquisition in open surgery, though variations in DP implementation limit direct comparison across studies. Enhanced instructional design aligning closely with DP principles may bridge gaps in training quality, providing a structured pathway.

Introduction

The use of simulation-based training has gained significant traction in the field of surgery, as it offers a safe environment for trainees to develop and refine their skills without compromising patient safety [1]. One particularly promising approach is the integration of deliberate practice into simulation-based training, which could enhance its effectiveness [2]. Deliberate Practice (DP), a concept widely studied in the field of expertise development, involves focused and repetitive engagement in challenging tasks intending to continuously improve performance. This approach is effective in various domains, including sports, music, and, more recently, medical education [2].

DP provides an evidence-based, structured recipe for training. The core components of DP are categorised into learner motivation, task design, feedback, and repetition [3] (Table 1). Repeated practice aimed at progressive improvement of skill requires feedback. Initially, this could be from a tutor, but with progressive improvement, the learners can assess and correct themselves. The entire process requires a "mental representation" [3] of the ideal performance, which is the cognitive framework that enables individuals to plan, monitor, and refine performance by comparing ongoing actions with an internal model of expert execution.

There are potential benefits in the synergy of Simulation-based surgical training (SBST) and DP. It can provide trainees with the opportunity to repeatedly practice specific surgical tasks or procedures, receive immediate feedback, and make adjustments to their performance until they achieve a desired level of proficiency [1, 4, 5]. This approach is particularly valuable in surgical education, where the ability to perform complex technical skills is crucial for patient outcomes. Better training is directly linked to better patient outcomes [6, 7]. Implementation of DP and SBST is challenging for multiple reasons, including limitations in resource allocation, time availability, and trainer capacity for supervision. While trainer engagement is essential, these challenges are often driven by broader systemic constraints within surgical education.

While deliberate practice is a well-established framework in cognitive psychology for achieving expert performance, its comprehensive application and explicit understanding within the field of surgical education may be inconsistent. These include the role of fidelity [8, 9], neglecting core elements of DP, and the best approach to structuring SBST [10]. This leads to variations in how its core elements are integrated and reported in simulation-based training studies. This systematic review aims to bridge this understanding by evaluating the explicit incorporation of DP principles in SBST for open surgery.

Methods

We performed a comprehensive review of randomised controlled trials and observational studies, including case-control, cross-sectional, and cohort studies on DP-guided SBST for open surgery. Modern surgical training distinguishes open surgery (A surgical procedure performed through a large incision that allows direct visualization and access to the operative field) from minimally invasive surgery (e.g. laparoscopic) because of the differences in psychomotor skills required. This review, therefore, was confined to open surgery.

The search for relevant literature was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [11]. The criteria based on Patient, Intervention, Comparator, and Outcome (PICO) are detailed below.

- Patients – Surgical trainees undergoing simulation-based interventions of open surgery
- Intervention – the use of DP
- Comparator – Other education interventions
- Outcome – Improvement in skill development

The review was registered on PROSPERO (CRD42024536662).

As a systematic review, this did not require approval from the institutional review board.

Literature search

MEDLINE, EMBASE, SCOPUS, ERIC, and Google Scholar were searched from inception to 31st January 2024 without limitations. The reference lists of the selected articles were searched to identify any further studies.

The search terms used to search MEDLINE are given below. Similar searches were performed on other databases (Supplementary data file 1). Because of the a-priori scope restriction to general open surgery, OB-GYN databases/journals were not systematically searched.

1. Deliberate practice OR Purposeful practice OR Mastery
2. Simulation OR Simulation-based learning OR Simulation-based teaching OR Skills learning
3. Surgery
4. 1 AND 2 AND 3

Study selection

Studies meeting the specified criteria were incorporated in the analysis. These criteria included: 1) Randomized controlled trials and observational studies (such as cross-sectional, case-control, or cohort studies), 2) investigating the impact of DP-informed SBST on enhancing surgical skills, and 3) having surgical trainees as the study participants. The term "Surgical skills" referred to any practical procedure outlined as a fundamental competency in the UK surgical training syllabus [12].

This review a-priori focused on open procedures in general surgery and its subspecialties to preserve methodological homogeneity across simulation platforms, trainee curricula, and assessment outcomes. Studies in obstetrics and gynecology (OB-GYN) and gastroenterology, and studies of non-surgeon staff groups (e.g., nursing), were therefore out of scope and not systematically searched or synthesized. We acknowledge OB-GYN as a surgical domain; this scope choice may limit transferability of findings to OB-GYN SBST.

The review specifically centred on the impact of DP-informed surgical skills training on surgeons' skill development, so articles addressing non-surgical, non-technical skills and human factors like teamwork were also omitted.

The search results were uploaded to Rayyan QCRI (https://rayyan.qcri.org/). Two independent reviewers (DPW, DW) initially screened the titles and abstracts of the identified studies. Subsequently, full-text articles of the chosen studies were perused. All located articles were written in English. No limitations were placed on the type of article, sample size, or educational techniques employed. Reference lists of the included studies were examined to detect additional studies not captured by the initial search strategy (snowball sampling). In cases where multiple publications presented data from the same population, the most recent or comprehensive study was included.

Excluded studies and the reasons for exclusion were recorded. Any discrepancies between the initial reviewers were resolved by a third reviewer (JV).

Data extraction and quality assessment

The extracted data comprised the authors' names, publication year, study design, study type, participant characteristics, Kirkpatrick assessment level [13], specific elements of the DP incorporated in the training program, and skill enhancement post-training. Two authors independently performed screening and data extraction (DPW, DW). Any discrepancies were addressed by consulting the senior author (JV) through discussions.

Elements of DP and their definitions were identified from the publications of Ericsson et al [3, 14, 15] (Supplementary table 1 - Definitions of elements of Deliberate Practice). The training programme of each article was perused to identify the adherence to the original components and definitions.

The quality assessment of the chosen papers was conducted using the Modified Medical Education Research Study Quality Instrument (MMERSQI) [16]. This instrument comprises 12 items across seven domains, with numerical scoring allocated to each item. The potential scores range from 23.5 to 100 (Supplemental Table 2 - Table - MMERSQI scoring table).

To evaluate bias in the studies selected, the RoB2 tool was employed for randomised trials [17], while the Risk Of Bias In Non-randomised Studies - of Exposure effects (ROBINS-E) and Risk Of Bias In Non-randomised Studies - of Interventions (ROBINS-I) were used for non-randomized studies [18]. The RoB2 tool consists of five scales and an overall bias risk judgment, categorising studies as low risk, some concern, high risk, or no information. On the other hand, the ROBINS-E and ROBINS-I tools assess studies based on seven domains, assigning ratings of low, moderate, serious, critical, or no information (Randomised Trials - Supplementary Table 3, non-randomised studies without an intervention - Supplementary Table 4, Non-Randomised studies with an intervention - Supplementary Table 5).

Results

The database search identified 585 articles. Three additional articles were identified through the references of the articles. Removal of duplicates identified 211 articles for title and abstract screening. This identified 44 articles for the full-text assessment. Twenty-two were eligible for data extraction and qualitative analysis. Figure 1 shows the PRISMA diagram.

Data from the included studies are shown in Tables 1 and 2.

Study design, participants, and structure of training

Seven studies were randomised controlled trials, and there were two non-randomized controlled trials and seven cohort studies. Fourteen studies recruited surgical trainees/residents as participants, while the remaining three focussed on medical students.

The majority (n=6) of studies centred on vascular anastomosis, while three each studied cardiac surgery and mastoidectomy (Table 2). Nine studies only used a single practice session. All other studies had multiple training sessions spaced over a few weeks to nine months.

Nine studies used a dry lab, while one each combined dry and wet lab, wet lab and simulator, and wet lab and real surgery. Four studies each used a wet lab and virtual reality (VR). In this review, 'wet lab' refers to training using biological tissue models, including cadaveric specimens, animal tissue, or organ models, to simulate operative conditions.

Most studies evaluated learning at Kirkpatrick levels 1 and 2, often in combination (Change in attitudes or knowledge). Li et al. [19] used a Kirkpatrick level 4a evaluation (impact on patient care or outcomes).

Elements of DP in SBST

There was a wide variation in the implementation of DP in skills training in the studies (Table 1).

Learner motivation

The DP model emphasises the importance of the learner's motivation to both attend to the task and improve their skill. Their explicit measurement is, therefore, essential in implementing DP.

Nesbitt et al. [20] recruited students who had expressed an interest in surgery. None of the other studies assessed the motivation of participants.

Task design

Tan et al. [21] assessed the prior experience of learners and used it in assigning participants to groups. They, however, did not use this information to structure the training. None of the other studies assessed prior experience.

Korte et al. [22] designed multiple difficulty levels, but all participants started their training at the same level. In the study by Feins et al [23], participants first performed individual tasks before performing the complete procedure. None of the other authors had different levels in their training activities.

Feins et al [23] focussed on a range of procedures in cardiothoracic surgery but did not indicate if the study included explicit instructions or demonstrations of the tasks. Hsu et al [24] also failed to provide explicit instructions to participants. Their study, however, focussed on tying knots, a basic surgical skill. All other studies provided clear descriptions of the expected task.

There were several methods used in teaching the skill, including videos [21, 25-27], reading material [21, 28], lectures [27, 29-32], and hands-on demonstrations [22].

Although the learning task was explicitly described in most studies, most authors did not evaluate the ease of understanding the instructions. Jensen et al [26] provided videos of the procedure before the programme and an in-person demonstration before beginning the task. None of the other studies indicated the ease of understanding.

Feedback

There were several types of feedback provided. These included human feedback from a tutor, self-assessment, or automated feedback. Automated feedback was always immediate, while tutor feedback could be given immediately or at a later date.

In 15 studies, the feedback was provided by a tutor and was immediate. One study [33] provided feedback on video recordings, but at a later date. Three studies used feedback provided by the simulator [24, 34, 35]. In the studies that encouraged self-assessment as a form of feedback, it was guided by either a video [36] or a checklist [21, 29].

Automated feedback from the simulators was also indicative of their performance. Three studies [25, 26, 37] did not state the nature of the feedback. In other studies, the feedback provided was indicative of the participants' performance.

Most studies provided the opportunity for remedial training following feedback, but several studies did not allow this [25, 26, 28, 37, 38].

Repetition

Only a handful of studies [20, 25, 26, 28, 37, 38] didn't permit remedial training or the opportunity for subsequent practice.

Most studies limited the duration of these sessions based on the effort constraint. The session duration ranged from 20 minutes [38] to four hours [23]. Some studies did not limit the training duration, permitting practice up to the entire day [28]. Furthermore, studies attempted to ensure adequate gaps between sessions to prevent fatigue [23, 29].

Effect of DP in improving learning outcomes

Most studies measured the skill before and after the training to assess improvement. Some studies measured the skill at intermediate time points [23, 30, 33] , and others measured the performance at every attempt [29, 34, 35].

All studies identified better learning following DP-informed simulation. Common outcome measures used included objective rating scales[19, 20, 29, 33, 39, 40], custom rubrics [22, 26], surveys and self-assessments [27, 35, 37], and speed [31, 32]. The study by Misra et al failed to identify an improvement in knowledge [38], but Li et al. [19] noted knowledge improvement.

Although studies reported an improvement in skill after SBST, this improvement did not directly correlate with the number of items of DP implemented. Several studies [21, 38] [25] also reported skill retention. The study by Petrosoniak et al. [31] assessed transfer validity.

Multiple studies [19, 28, 40] identified that the early introduction of SBST is better.

Study quality and bias assessment

Four of the six RCTs had a low risk of bias according to the ROB2 score, while the remaining two had some concerns. There was a wide variation in the bias in the non-RCTs. Five studies had some concerns, while eight had a high risk of bias (Table - Supplemental Digital Content 1 - Randomised Trials, Table - Supplemental Digital Content 2 - Non-Randomised studies without an intervention, Table - Supplemental Digital Content 3 - Non-Randomised studies with an intervention).

The quality of the studies, measured by (MMERSQI), ranged from 43 to 87, with RCTs consistently having higher scores.

Discussion

This systematic review attempted to explore the utility of DP-informed SBST in developing open surgical skills. In summary, our results confirm that DP is an effective tool for designing SBST curricula. There was a wide variation in the implementation of DP in simulation training, with learner motivation being the least emphasised and demonstration of the technique being the best emphasised. Most studies were confined to Kirkpatrick level 1 or 2 assessments. Most studies analysed the skill before and after the intervention, while some measured the skill throughout the training. Learning with DP-informed SBST was better than control groups, but the improvement was not proportionate to the adherence to the framework. The study quality varied significantly, even among RCTs. The strength of the findings is most affected by this. These findings are similar to the findings of the systematic review on DP-informed simulation for laparoscopic training by the authors.

Surgical training traditionally follows a Halstedian approach [41] of increasing clinical responsibility through a hierarchical, apprenticeship-based model. Work hour restrictions and ethical concerns have led to resistance to this format [42, 43]. Despite their theoretical benefits, SBST programs have often failed to deliver the promised learning outcomes [33, 39]. The sole availability of a simulator is inadequate for a meaningful educational experience [44]. One potential culprit is suboptimal instructional design [45]. Integrating DP into SBST allows surgical trainees to engage in repetitive, goal-oriented tasks with expert feedback, enhancing skill mastery and accelerating the path to expert performance. Although this hypothesis is grounded in existing evidence, it has not been evaluated through a systematic review previously.

Of the main domains of DP, learner motivation was universally ignored. Pre-training motivation is predictive of learning outcomes [46]. The correlation between motivation and learning was reported to be 0.45 by Facteau et al [47]. Motivation could be extrinsic and intrinsic. For continued practice in DP in SBST, intrinsic motivation is mandatory [44]. The lack of emphasis on learner motivation could be one reason for the poor correlation we saw between components of DP and outcomes.

Task design is also a key component of DP. Of its sub-components, providing a starting level appropriate for individual trainees' competence was universally ignored. Only Feins et al. [23] provided training which had multiple difficulty levels. All others had training of the same difficulty. Most studies provided an explicit demonstration of the expected tasks, some in multiple forms. The authors did not, however, state if these instructions were easily comprehended by the participants.

DP-informed SBST differs from standard training in providing feedback, allowing for reflection on their performance for improved performance [48]. Human feedback is superior to automated VR feedback metrics [49], but human resource limitations, such as high instructor commitment and expensive equipment, make it challenging to implement DP-informed SBST in existing training programs. There are several potential solutions for this. Introducing DP early in training can improve learning outcomes[50], as it encourages effective mental representation for self-directed practice [15]. Providing intensive supervision early in training can be cost-effective and enable learners to use VR systems effectively. Video recording of student training can reduce tutor time commitment [51]. The third option is the provision of an explicit objective tool for self-assessment. The latter will require collaboration between trainers, course developers, and accrediting agencies.

Unlike minimally invasive surgery, open surgery is not routinely videoed. Despite this, several studies used video recording for participant assessment [30, 33, 38]. While the collation of these videos from multiple trainees minimises the time and resource commitments of training programmes, they violate the DP principle of immediate feedback. Another alternative for minimising tutor resources is the use of peer feedback. Peer feedback for surgical training has been used successfully [52-54]. The results of Vaughn et al [54] indicated that peer feedback produced a better outcome than faculty feedback.

Self-assessment during SBST has been utilised earlier [36], and existing evidence suggests that learners can accurately identify their mistakes [55]. Moorthy et al. identified a good correlation between self and expert assessment [56]. The accuracy of self-assessment improves with experience [56]. Guided simulation without feedback is not effective [57, 58]. Empowering learners with a guided self-assessment tool, in contrast, results in improved learning outcomes [59].

Only one study [24] in this series evaluated generic surgical skills. All other studies focussed on intermediate skills (e.g. bowel anastomosis [25]) or surgical subspecialties (e.g. cardiac surgery). The studies on cardiac and vascular surgery often recruited senior trainees or consultant Surgeons. Existing evidence indicates that early introduction to SBST provides better outcomes [50]. These results contrast with DP-informed SBST in laparoscopic surgery. Furthermore, compared to our findings on training in minimally invasive surgery, there was a greater emphasis on whole-task training in the included studies.

As a systematic review, our findings are limited by the strength and quality of the included publications and by our a-priori scope restricted to open procedures in general surgery and its subspecialties. The heterogeneity of study quality and risk of bias is a major limitation and precluded meta-analysis. Additionally, we limited the scope to the development of psychomotor skills in surgical procedures and purposely ignored other domains of expertise, like clinical decision-making and communication. Furthermore, there was significant heterogeneity in the participant characteristics, learning outcomes, and training orchestration. The findings and the gaps in knowledge, however, provide direction for future researchers to consolidate pedagogy in study design. It also provides practical guidance for course designers to maximise learning. An evidence-based checklist of best practices needs to be developed but is beyond the scope of the present article.

The observed wide variation in the implementation of DP in simulation training and the inconsistent correlation between the number of DP elements and learning outcomes suggest a potential disconnect between the established theoretical tenets of deliberate practice from cognitive psychology and its practical application in surgical education. Authors of primary studies may, for instance, naturally incorporate elements like repetition and feedback without fully adhering to other critical, but less intuitive, DP components such as structured assessments of learner motivation or individualized task design based on prior competence. This systematic review also aims to highlight this disconnect and encourage a comprehensive implementation of DP in SBST. Similar to how modern validity frameworks are applied retrospectively to studies using older terminologies, this review applied the established DP framework to evaluate contemporary SBST literature. The observed heterogeneity and variations in DP implementation reflect the challenge of classifying elements from studies that may not have been explicitly guided by the full theoretical construct of deliberate practice.

Conclusions

Deliberate practice is a useful tool to design and deliver surgical training through simulation. The included studies confirm the effectiveness of DP-informed SBST for open surgery, with consistently better learning outcomes compared to standard educational techniques. The variable adoption of the elements of DP in number and definition into SBST remains the biggest confounder in interpreting the existing evidence. Future researchers and educators should, therefore, pay careful attention to the instructional design of their training programmes, with strict adherence to the original definitions of the elements of DP.

Funding

None

Conflicts of interest

None of the authors declare any conflicts of interest.

Contributor roles

Conceptualization, methodology, writing – review and editing – DPW, JV. Formal analysis, writing original draft – DPW. Supervision – JV.

Acknowledgement

The authors would like to acknowledge the contribution of Dileesha Wickramasinghe (DW) in the data collection for the review.

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Legend of tables

Figure 1 – PRISMA diagram

Table 1 - Adherence to elements of DP

Table 2 - Overview of the included studies

Supplemental Digital Content 1 - Table - ROB2 classification

Supplemental Digital Content 2 - Table - Risk Of Bias In Non-randomised Studies - of Exposure effects (ROBINS-E)

Supplemental Digital Content 3 - Table - Risk Of Bias In Non-randomised Studies - of Interventions (ROBINS-I)

Supplemental Digital Content 4 - Table – Definitions of elements of Deliberate Practice

Supplemental Digital Content 5 - Table - MMERSQI scoring table

Figure 1 - Prisma Flow diagram. (Adapted with permission from the PRISMA Group) Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097.