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A systematic examination of preoperative surgery warm-up routines

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Abstract

Background: Recent evidence indicates that a preoperative warm-up is a potentially useful tool in facilitating performance. But what factors drive such improvements and how should a warm-up be implemented?

Methods: In order to address these issues, we adopted a two-pronged approach: (i) we conducted a systematic review of the literature to identify existing studies utilizing preoperative simulation techniques; (ii) we performed task analysis to identify the constituent parts of effective warm-ups. We identified five randomised control trials, four randomised crossover trials and four case series. The majority of these studies reviewed surgical performance following preoperative simulation relative to performance without simulation.

Results: Four studies reported outcome measures in real patients and the remainder reported simulated outcome measures. All but one of the studies found that preoperative simulation improves operative outcomes- but this improvement was not found across all measured parameters. Whilst the reviewed studies had a number of methodological issues, the global data indicate that preoperative simulation has substantial potential to improve surgical performance. Analysis of the task characteristics of successful interventions indicated that the majority of these studies employed warm-ups that focused on the visual motor elements of surgery. However, there was no theoretical or empirical basis to inform the design of the intervention in any of these studies.

Conclusions: There is an urgent need for a more rigorous approach to the development of 'warm-up' routines if the potential value of preoperative simulation is to be understood and realised. We propose that such interventions need to be grounded in theory and empirical evidence on human motor performance.

1 Introduction

2 Introduction

It is widely acknowledged that there are few systemic protection mechanisms that can prevent the occurrence of technical error in surgery[1]. A recent survey of practicing surgeons indicated that technical errors are common in the operating theatre (although they are often unreported) [2]. It has become increasingly more challenging to address the prevalence of technical error for a variety of reasons. These reasons include an increased emphasis on minimally invasive surgery - which is a more technically demanding task compared to open surgery. In parallel, there has been a reduction in training hours[3] (see the impact of the European Working Time Directive[4] and the Modernising Medical Careers report[5] on United Kingdom training programs) and these changes have been mirrored in the United States[6] and Canada[7], among others.

How can we address these issues within health services that explicitly state that patient safety is their overarching priority[8, 9]? One solution seems to lie in simulation. The substantial reduction in training time, alongside the increasing complexity of surgical procedures, has driven an exponential increase in the use of simulation for education. The approach is promising - there is some evidence to suggest that skills learnt in simulated environments can transfer into the operating room[10, 11] - greatly enhancing potential learning opportunities for trainees. The nature of surgical simulators enables substantially more practice relative to the traditional models of surgical education. The rationale is that increased exposure to procedures in a controlled environment should reduce the amount of technical errors in surgery over the long-term - a claim that remains to be empirically established.

More recently, researchers have been investigating whether these simulators might yield shorter-term gains for trainees and experts alike, through the implementation of pre-operative “warm-ups” [12, 13]. The idea of warming up for surgery has largely been borrowed from sports medicine: there is a long history of elite athletes performing warm-up routines. The benefits of warm-up appear to extend to areas beyond sport - for example, opera singers warm their vocal chords before singing to an audience. In surgery, recent systematic reviews of the literature indicate that warming up (most often on a surgical simulator- we refer to this process as "preoperative simulation") is an approach that improves a surgeon's performance in the operating room. Whilst the evidence is promising, and the analogy appears to fit well - after all, surgery is a task that demands a high level of performance (with substantial risks associated with task failure), there is no clear understanding of *how* a warm-up might benefit the specific demands of surgery. This is a serious shortcoming and a key barrier to its implementation.

A poorly designed warm-up routine could potentially have a plethora of negative consequences: from wasting precious clinical time to negatively impacting on performance in the operating theatre. If the potential of warming up is to be realised, we need a careful consideration of the processes that facilitate performance. To this end, we adopted a dual-processing framework from cognitive science to interrogate warm-up methodologies to identify their constituent parts.

Surgical performance can broadly be separated into two types: (i) low level 'motor decisions' such as the completion of a planned sequence of actions, mastered through repetitive practice; and (ii) comparably higher-level offline 'cognitive decisions' generated through education and experience. The majority of human behaviour can be understood as the product of a complex interplay between cognition and motor control[14], with neuroimaging evidence indicating overlapping cortical and subcortical networks[15–18]. In surgery, this interaction can manifest itself in multiple ways: knowing the procedural steps necessary to complete an operation without the requisite manual dexterity can be disastrous. Conversely, motor proficiency without appropriate understanding or attention is equally problematic.

Based on this perspective on human performance, there are good theoretical reasons for why preoperative simulation might prove to be effective. Preoperative simulation could be used to engage cognitive and motor processes in a variety of ways. For example, physically rehearsing an operation before performing that procedure *in vivo* could allow surgeons to rapidly refine, update and actively engage internal models of the external world to promote successful actions: facilitating recall of the sequence of steps required during the operation as well as rehearsing strategies that could be deployed if complications arise. Additionally, or even alternatively, the use of preoperative simulation that focuses on visual motor processes might assist surgeons in calibrating their motor system to the visual and motoric transformations inherent in minimally invasive surgery.

To understand the processes driving effective warm-up, we conducted a systematic review of the literature on preparation and surgical success. After identifying studies examining the efficacy of warm-up, we considered the task characteristics of a successful warm-up and the performance metrics that are modulated by this process.

3 Methods

We developed a search strategy according to the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidance[19]. In order to ensure comprehensive coverage of the areas related to this research question, we conducted an electronic search of relevant databases (Cochrane Library (1995-), PubMed, PsycINFO (1967-), ERIC (1964-) and Google Scholar) utilising the following key words: “Surgery”, “Laparoscop*”, “Minimally Invasive”, “Simulat*”, “Educat*”, “Technolog*”, “Warm-up”, Warm-up”, “Preparation”, “Planning”, “Rehearsal”, “Mental Rehearsal”, “Cognitive”, “Decision Making”, “Decision”, “Outcome”, “Performance”, “Preoperative” and “Pre-operative”. Key words were grouped using “AND” or “OR” terms. Bibliographies of relevant studies and the “related articles” link in PubMed were used to identify any additional studies. All citations and abstracts identified were thoroughly reviewed. The last date for this search was 1st May 2015.

3.1 Inclusion and Exclusion Criteria

All included studies analysed the effect that a preoperative simulation had on subsequent surgical performance (simulated or real-life). Studies were restricted to those that examined a deliberate intervention prior to an operation or procedure rather than a training regime or educational programme. There was no restriction applied to the type of skills examined. All study designs were considered for inclusion. Studies published only as an abstract or unpublished report were excluded from further analysis. All studies were carefully evaluated for duplication or overlapping data and such reports were removed.

3.2 Study Selection

Two authors (TWP and SP) independently performed the search according to the strategy described above. Both authors independently reviewed the identified abstracts and excluded those that did not meet the inclusion criteria. If no abstract was available or the abstract did not contain adequate information, the full article was reviewed. Differences of opinion between the two authors (TWP and SP) on the selection of studies were resolved by consensus with the senior author (JPAL). If consensus could not be reached the protocol indicated that the senior author's decision would be considered final – a process that was not required during study selection.

3.3 Data Extraction, Outcome Measures and Statistical Analysis

Authors TWP and SP, using a standardised proforma, performed data extraction independently. As with study selection, the research protocol indicated that disagreements would be resolved by consensus with the senior author (JPAL). The following parameters were recorded: study characteristics (first author, year of publication, place of publication), population characteristics and outcomes of interest. The primary outcome of interest was surgical performance, however defined. Of secondary interest were the additional outcome measures reported by each study. The heterogeneity of included studies prevented a quantitative synthesis of reported outcomes. Finally, to understand the key drivers for effective warm-up, we also examined the characteristics of the warm-up task.

3.4 Risk of Bias Assessment

The method for objectively assessing the risk of bias of included studies depended on the type of study. Randomised control trials were reviewed using the Cochrane risk of bias tool[20], while cross-over trials were analyzed using a modified version of a tool developed by Mills et al. [21].

4 Results

Four hundred and eighty-three articles were identified by the search strategy described above. Following a review abstracts, full articles and references, 13 studies were included in this systematic review (see **Figure 1**).

---INSERT FIGURE 1 HERE---

Figure 1. PRISMA flow chart showing the selection of articles for review

4.1 Study Characteristics

Four randomised control trials (RCTs)[22–25] and four randomised cross-over studies[26–29] were included- all of which reviewed operative outcomes following a practice of technical skills prior to an operation versus no practice. A further four studies were case studies, two compared a technical skills practice to no practice[30, 31] and two[32, 33] did not contain a control group. One RCT[34] examined the effect of mental practice prior to an operation on subsequent laparoscopic performance.

Eight of the studies[22, 24, 25, 29–31, 33, 34] (45,47,48,52-54,56,57) examined the effect of preoperative simulation on general surgery procedures, three looked at obstetrics and gynaecological procedures[23, 26, 32] and the last two examined the effect of preoperative simulation on endovascular[27] and urological[28] procedures. Four of the studies[22, 28–30] examined outcomes in real patients, the other nine[23–27, 31–34] reviewed simulated outcomes.

4.2 Assessment of Bias

There was significant variability in the quality of studies included. Only one study[25] was judged to be at low risk of bias: **Table 1, 2**. Five studies[22, 23, 25, 26, 29] were found to be at low risk of randomisation bias, with explicit detailing of the methods of randomisation and allocation concealment employed. Two studies[22, 25] reported *a priori* power calculations, but one of these studies[22] calculated that a substantially larger number of participants would be required than were actually recruited- thus indicating a lack of statistical power in this study. Relatedly, the sample sizes across all studies was generally modest, with only one RCT or cross-over study[25] reporting more than 20 participants per group. The included case studies could not be objectively assessed by the methods used to review the RCTs and cross-over studies, but each demonstrated methodological shortcomings, as discussed below.

---INSERT TABLE 1 & 2 HERE---

4.3 Reported Outcomes

The included articles report 103 different outcome metrics, often combined to form a compound score. A summary of the main findings of each study is detailed in **Table 3**. Twelve[23–34] of the thirteen included manuscripts concluded that a preoperative simulation improves subsequent surgical performance. Importantly, no study found preoperative simulation to have a detrimental effect on surgical performance or suggested any negative aspect of preoperative simulation.

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4.4 Studies Reporting Global Rating Score

The most often reported outcome was the effect of preoperative simulation on a global rating score of performance. Seven of the included studies[22, 23, 27–30, 34] reported this outcome metric - defined as a summary of objective assessment parameters by an expert examiner. Nine global rating scales[22, 23, 25, 35–41] were employed in the seven studies, with all but two studies reporting a different global rating scale. In a majority of studies, validated global rating assessments were used. In three studies[22, 28, 30] a modification of a previously published global rating scale was employed.

In two RCTs[23, 34] and one cross-over trial[29], the authors reported unequivocally that preoperative simulation improves subsequent real-world operative performance, as assessed by a global rating scale. Two cross-over trials[27, 29] reported ambiguous findings for the effect of preoperative simulation on surgical performance; the first study[27] reported a significant effect as measured by one global rating scale, but no effect according to another also-reported scale. The second study[28] found a significant improvement in one assessed task, but not another. One RCT[22] and one cross-over trial[30] found that preoperative simulation had no effect on subsequent performance, as judged by a global rating scale.

4.5 Studies Reporting Performance Time

Five of the included studies[24, 25, 27, 31, 33] reported `pure' performance time-defined as the time taken to perform an assessed task. Those articles that reported duration as part of a global rating scale were not included as such studies have been discussed above. The authors in one RCT[25] and one case study[26] reported that preoperative simulation shortens subsequent performance time in a simulated environment. In one cross-over trial[27] and one case study[33] equivocal results were reported, with preoperative simulation reducing the time of some performance metrics, but not all. Finally, in only one RCT[24] did preoperative simulation not affect the time taken to perform simulated laparoscopic surgery.

4.6 Studies Reporting Time-based Score

In three studies[26, 31, 32] a time-based score was reported, either in combination with errors made (resulting in a time penalty) or as the number of occasions a task was performed within a set time. The authors in one case study[32] found that preoperative simulation increases the number of times a laparoscopic task can be performed within a set time period. The authors in another case study[31] found that preoperative simulation reduces time taken and errors made during the placement of intracorporeal sutures, but not the time taken and errors made during two other laparoscopic tasks. Finally, in one cross-over study[26] it was found that preoperative simulation did not improve simulated laparoscopic performance as assessed by a time-based score.

4.7 Kinematic performance

The authors of four studies[24, 25, 28, 33] reported outcome metrics generated by the laparoscopic simulator used during their experiments. Hand and tool movement smoothness and instrument path length were reported, but there was no concordance across the studies; some reported significant results in certain outcome metrics while others did not.

4.7.1 Error frequency

In four studies[24, 25, 28, 33] the effect of preoperative simulation on the number of errors made during a procedure (determined by a simulator or expert assessor) was reported. The authors of one RCT[24] and one case study[33] found that preoperative simulation significantly reduced the number of errors that occurred during simulated laparoscopic performance. Conversely, another RCT[25] found that preoperative simulation did not affect error frequency.

4.8 Subjective Evaluation

The authors of one cross-over study[27] explored participants' perception of how useful they found the preoperative simulation and whether they believed simulation improved their subsequent performance. This was assessed by a questionnaire utilising a five-point Likert scale. Participants reported that they felt patient-specific simulation to be more helpful than generic simulation, which was more useful than no simulation. Participants also reported that they felt patient-specific simulation helped with decision-making, improved safety, increased their confidence levels and resulted in reduced preoperative anxiety (of the operator).

4.9 Studies Examining Outcomes in Real Patients

In four studies[22, 28–30], the effect of preoperative simulation on real patients was examined. Three of these studies[28–30] concluded that pre-operative simulation improves real operative outcomes. Weston *et al.*[22] found preoperative simulation had no effect on subsequent performance. However, as discussed above, Weston *et al.* performed an *a priori* power calculation that demonstrated a larger number of participants than were actually recruited would be required to achieve the requisite statistical power and consequently, the absence of a significant result may reflect a Type II error.

5 The Characteristics of Successful Warm-Up

In order to explore the underlying mechanisms for the observed performance improvements through preoperative simulation, we performed a rudimentary analysis of the tasks performed though a dualistic framework of surgical performance- parsing cognitive and motor processes[42] (**Table 4)**.

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5.1 The Warm-Up Tasks

Three mediums of simulation were employed by the included studies; in seven studies a virtual-reality simulator[25, 27–30, 33], in four a laparoscopic box trainer[21, 23, 26, 32], and in two, video-games[24, 31]. Though various forms of simulation were employed, there was a general concordance across the studies as to what constituted preoperative simulation. All studies, except one[34], used a similar or simplified motor task as preoperative simulation before performing the assessed task.

Whilst acknowledging that motor and cognitive processes do, and must, work in concert, and although necessarily speculative in nature, investigation into the degree of engagement of each system could assist with the future development of optimal preoperative simulation interventions. Thus, we categorised the preoperative simulation routines employed in each study into those more likely to engage motor or cognitive processes.

The majority of included studies[22–33] tapped into motor related tasks in their preoperative simulation routines. For example, in most of these cases, a simplified simulated task (*cf.* the assessment task) was used to prepare the participants for surgery (real-life or simulated) and thus, demanded a repetition of motor action. Two studies[27, 30] had, what appears to be a more even distribution of cognitive and motor demands in their preoperative simulation and one study relied on cognitive alone (complete absence of motor action)[34].

One RCT[34] reported participants' mental imagery following mental practice (experimental group)- defined as "the cognitive rehearsal of a task in the absence of overt physical movement"[34]- or an online academic activity (control group) immediately prior to performing a simulated laparoscopic cholecystectomy. The authors reported undertaking structured mental practice significantly improved participants' mental imagery of a procedure. Finally, in one cross-over study[28] it was found that preoperative simulation improved attention, reduced distraction / drowsiness and reduced mental workload in comparison to no warm-up.

6 Discussion

Consistent with previous evidence on the potential value of warm-up, all but one of the studies included in this review concluded that preoperative simulation significantly improves subsequent surgical performance. Thus, it appears that surgeons may benefit from engaging in formalised preparation routines before carrying out a procedure. However, the heterogeneity of the studies identified means that there are a number of outstanding questions that must be addressed regarding how warm-up should be effectively implemented. We discuss these issues, alongside the strengths and limitations of the reviewed studies, and present perspective on future research below.

The studies reported here worked outside any obvious theoretical framework- as evidenced by the narrow focus of preparatory procedures employed. The interventions were biased towards a motoric interpretation of preoperative simulation. As outlined in the introduction, human behavior can be understood as an interaction between cognitive and motor systems. The studies reviewed here predominantly focused on more automated behaviours at the neglect of controlled cognitive processes. We speculate that interventions relying on both are likely to produce greater benefit than focusing on a single process alone[43].

We suggest that a more rigorous approach to the development and implementation of preoperative simulations is necessary. A rich history of theoretical and empirical approaches to understanding human performance exists in cognitive science[14, 42, 44–50]– employing approaches from this body of work and mapping surgical simulation to our understanding of human decision-making should help maximise the potential of this intervention.

Central to our investigation was the examination of the outcome metrics that might be influenced by warm-up. We found a high number of outcome metrics within and across the studies reviewed (see **Table 3**). Whilst this is problematic, difficulties in deducing a clear picture from the literature are compounded by the finding that only four studies[22, 23, 29, 32] showed concordance between all reported outcome measures within the studies. Three of these studies[23, 29, 32] concluded that preoperative simulation improves surgical performance. One study[22] (45) reported that preoperative simulation does not affect subsequent performance but, as noted earlier, this study lacked sufficient statistical power. The nine other studies[24–28, 30, 31, 33] included in this review reported significant results in some, but not all, recorded outcome measures. All of these studies concluded overall that preoperative simulation improves surgical performance, but only two studies[25, 28] (48,51) include an explanation as to why significant results were prioritised over non-significant results.

The selective reporting of significant outcome measures may bias the conclusions drawn from these studies. This is an issue that generalises - a consensus opinion on outcome reporting is imperative to allow effective meta-analysis of results and permit a high quality evidence base to be developed. Surgical education and training should follow the example set by clinical research by agreeing a set of standardised outcomes to report[40, 51–53]. Whilst a comprehensive discussion of this issue is beyond the scope of the current review, standardising outcome reporting is particular necessary, and most amenable, in the assessment of simulated surgical skills. Surgery performed on real patients can be assessed by reviewing patient outcomes (although none of the included studies reported such data) - the gold-standard of outcome reporting.

Simulation-based research often relies on outcomes of convenience. For example, one of the most frequently reported outcome metrics in this systematic review was performance time. While it is recognised that expert performance is faster than novice performance[10, 11], the converse is not necessarily true, i.e. faster performance does not necessarily confer better quality surgery[54, 55]. The same applies to simulator-generated metrics; for example, while experts tend to have smoother movements, having smoother movements does not necessarily mean the operator is an expert. Consequently, such metrics, particularly when reported without additional objective or subjective data, can only be interpreted with considerable caution. Despite this, the majority of reported outcomes demonstrate that preoperative simulation does have a beneficial effect on subsequent surgical performance, in both simulated and real-patient environments.

In this review, studies were included irrespective of the type of surgical skill being examined. The heterogeneity of the included studies can be viewed as a strength of this review as the generic concept of preoperative simulation can be explored across multiple surgical specialties, using a variety of assessment methods. Conversely, the disparity between studies and the number of different outcome metrics used prevent a quantitative synthesis of reported outcomes. In addition, it is worth noting that because of the paucity of studies in the literature, designs that are often excluded from systematic reviews have been included.

Further research is clearly required in this area, but despite the limitations of the studies reviewed, the data taken as a whole indicate that preoperative simulation could prove to be a highly promising avenue for future interventions. No study demonstrated, or even implied, that preoperative simulation has a detrimental effect on subsequent surgical performance. Anecdotal evidence suggests that many surgeons currently employ some form of ad-hoc informal preoperative simulation already. The ease of implementing preoperative simulation with the potential for profound changes in patient safety leads us to identify this as a critical area for further study.

In conclusion, evidence from the literature suggests that preoperative simulation improves subsequent surgical performance, both in simulated and real-patient environments. Nevertheless, there is a need for further rigorous, empirically and theoretically driven interventions to maximise any benefit that preoperative simulation might yield. The next challenge for this field is to develop formalised, theoretically grounded, approaches that can be integrated into hospital processes to optimise the practice of surgery.

Author Disclosures

Mr. Pike, Mr. Pathak, Dr Mushtaq, Dr Wilkie, Professor Mon-Williams and Professor Lodge have no conflicts of interest or financial ties to disclose.

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Table Legends

Table 1A - Risk of bias table for Plerhoples *et al.*

Table 1B - Risk of bias table for Weston *et al.*

Table 1C - Risk of bias table for Chen *et al.*

Table 1D - Risk of bias table for Lendvay *et al.*

Table 1E – Risk of bias table for Arora *et al.*

Table 1F - Risk of bias summary table for included RCTs

Table 2 - Risk of bias table for included cross-over trials

Table 3 - Outcome measures reported by included studies

Table 4 – Summary of the underlying cognitive processes examined by the included studies