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ORIGINAL SCIENTIFIC REPORT

Implementation of a Surgical Simulation Care Pathway Approach to Training in Emergency Abdominal Surgery

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Abstract

Background Simulation-based care pathway approach (CPA) training is a novel approach in surgical education. The objective of the present study was to determine whether CPA was feasible for training surgical residents and could improve efficiency in patients' management. A common disease was chosen: acute appendicitis.
Methods All five junior residents of our department were trained in CPA: preoperative CPA consisted in virtual patients (VPs) presenting with acute right iliac fossa pain; intraoperative CPA involved a virtual competency-based curriculum for laparoscopic appendectomy (LAPP); finally, post-operative VP were reviewed after LAPP. Thirty-eight patients undergoing appendectomy were prospectively included before (n = 21) and after (n = 17) the training. All demographic and perioperative data were prospectively collected from their medical records, and time taken from admission to management was measured.
Results All residents had performed less than 10 LAPP as primary operator. Pre- and intraoperative data were comparable between pretraining and post-training patients. Times to liquid and solid diet were significantly reduced after training [7 h (2–20) vs. 4 (4–6); P = 0.004, and 17 h (4–48) vs. 6 (4–24); P = 0.005] without changing post-operative morbidity [4 (19%) vs. 0 (0); P = 0.11] and length of stay [48 h (30–264) vs. 44 (21–145); P = 0.22].
Conclusions CPA training is feasible in abdominal surgery. In the current study, it improved patients' management in terms of earlier oral intake.

Introduction

Both technical and non-technical skills are essential in the training of surgeons [1]. Until now, training out of the operating room (OR) predominantly consisted of improving intraoperative technical skills [1–3]. This type of training has already demonstrated its positive impact for basic laparoscopic skills in the OR [4–7]. Non-technical skills are needed not only in the OR, but also in perioperative care. Indeed, Pucher et al. showed that ward round quality had some impact on patients' outcomes in surgery [8].

Most published perioperative care training regimens are experiential or didactic, but not interactive between the trainees and the patients, i.e. that the patients themselves

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(virtual or actors) provide data about their chief complaint, history and examination. The best-known field of research for this type of interactive training is the simulated ward, a high-fidelity model using actors to play patients within an environment pertaining to a real surgical ward [9, 10]. However, the simulated ward is expensive and presents both access issues and time constraints. An attractive field of interactive training is the use of online virtual patients (VPs), which showed effectiveness for residents, using pre- and post-operative scenarios [11, 12].

Ideally, training out of the OR should include both intra- and perioperative care. A care pathway approach implies both technical skills training on a simulator and training in pre- and post-operative care. The purpose of perioperative training is to improve both decision-making and knowledge. In a previous study, we designed a curriculum to teach pre-, intra- and post-operative surgical care (a care pathway) for acute appendicitis [13]. We used VP for the pre- and post-operative phases, and a virtual simulator for the intraoperative phase, which was discriminant between residents and senior surgeons. The objectives of the present study were to implement such a simulation-based curriculum as applied to care of real patients, assess its feasibility in a surgical training program and measure its impact on patient outcomes.

Methods

Study population

This was a prospective one-centre study, performed in the department of digestive surgery of St. Mary's Hospital, Imperial College Healthcare NHS Trust, London. The study was approved by the NRES Committee London—Central. After providing informed consent, thirty-eight consecutive patients undergoing appendectomy between 8 am and 7 pm were included before (n = 21) and after (n = 17) the training of residents during a 6-month period. The time schedule for enrolling the patients was chosen to ensure that time to oral intake would not be biased between groups.

The data included demographic data, such as age, gender and American Society of Anesthesiology score (ASA score) [14]; preoperative data, such as Alvarado score [15], rebound tenderness, fever, leukocytosis, and results of ultrasound (US) or computed tomography (CT) scan. In addition, time from admission to evaluation by a surgical resident, imaging and administration of antibiotics was measured. Intraoperative data, such as time from admission to surgery, type of approach (i.e. laparoscopic or open), conversion to open surgery, rate of difficulty (on a 1 to 5 scale), Objective Structured Assessment of Technical Skills (OSATS) self-rating [16], intraoperative findings (i.e. normal, inflamed or perforated appendix, abscess, other diagnosis), intraoperative complications, and operative time were collected. Post-operative data included post-operative morbidity (according to Dindo's classification) [17], including gastrointestinal complications, additional surgery and mortality, duration of antibiotics, type of analgesia, post-operative pain at Day 1 (according to an analogue visual scale (AVS) from 1 to 10), time to liquid and solid diet, length of stay, and confirmation of appendicitis on histopathological analysis.

Care pathway curriculum

The curriculum design was previously published (Fig. 1) [13]. In summary, preoperative training consisted in 4 VP, designed in the virtual world of Second Life™ (Linden Research Inc., San Francisco, CA, USA). All presented with acute right iliac fossa (RIF) pain in the emergency room (ER). Not all of the VP actually had acute appendicitis; thus, not all required an operation. The objectives of these cases were to elicit the relevant clinical information from the history and examination, establish the pertinent investigation findings, determine the correct diagnosis and initiate an appropriate evidence-based management plan [18, 19]. Preoperative VP 1 was a 24-year-old man with acute appendicitis. Management plan was fasting, intravenous (IV) fluids, analgesia, antiemetics and antibiotics, proceed to abdominal CT scan to confirm diagnosis, and then proceed to appendectomy. VP 2 was a 28-year-old man with terminal ileitis from Crohn's disease. VP 3 was a 22-year-old woman with a background gynaecological history of heavy menstruation and a diagnosis of haemorrhagic ovarian cyst. Finally, VP 4 was a 58-year-old man with associated weight and appetite loss, as well as anaemia. His suspected diagnosis was caecal cancer.

In practice, the trainee logs from a laptop on Second Life™, chooses a patient on a board in an emergency ward (he "activates" the case by clicking on this central board), then goes towards the patient and has the choice to click on history or examination. If he clicks on history, he can interrogate the patient on the type of pain, its localization and intensity, or if he has nausea/vomiting, etc. The patients will then "answer" each question asked by the trainee. When the trainee clicks on examination, he can then "palpate" the abdomen by clicking on it, or ask if bowel sounds are present. A monitor, placed next to the patient, indicates his temperature, blood pressure and pulse. The trainee can then ask for investigations (blood tests, CT scan or US scan) and choose his management as described above. If the management or the diagnosis is correct, a message appears such as "the senior consultant agrees with

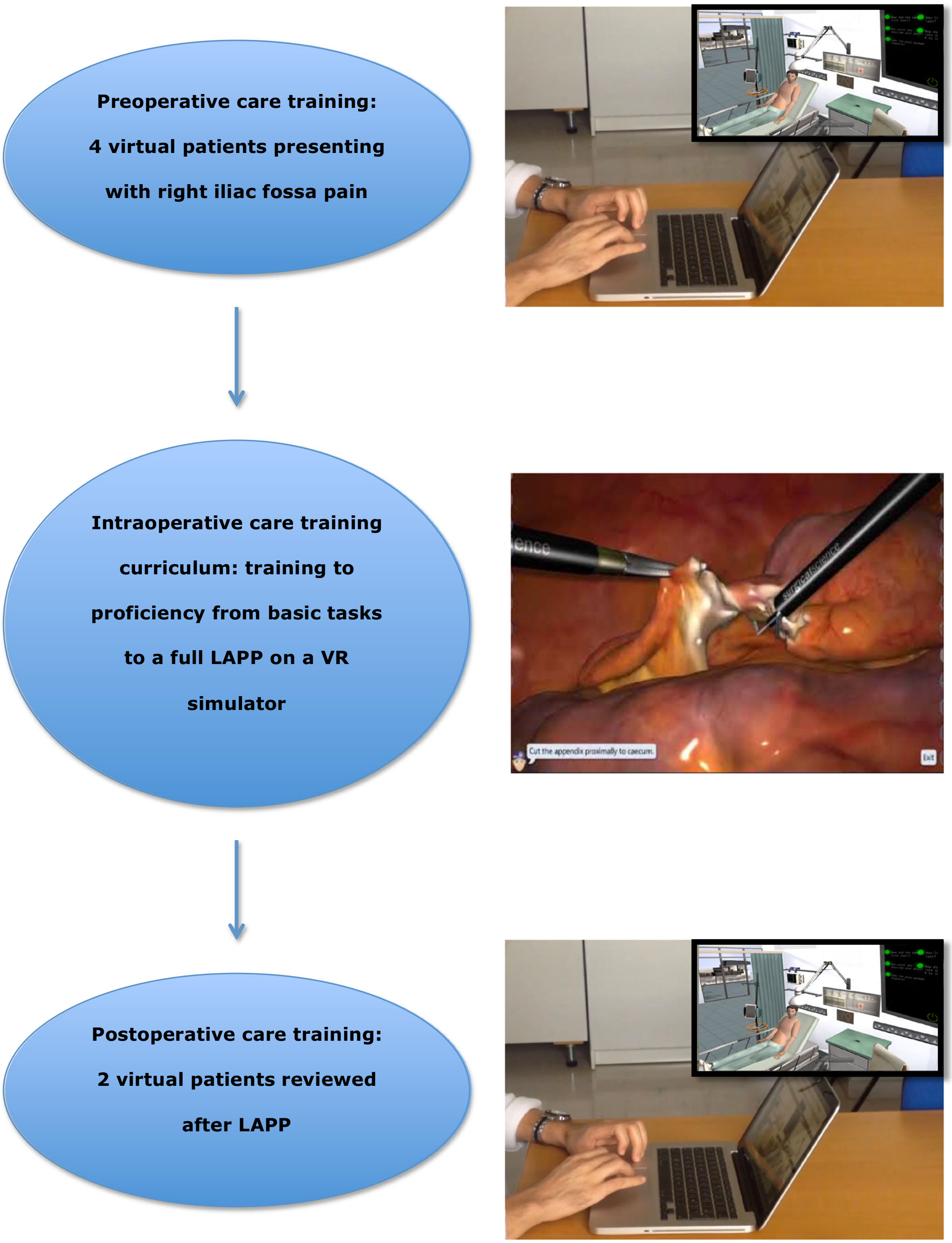

Fig. 1 Design of the simulation-based care pathway approach. LAPP: laparoscopic appendectomy

your diagnosis/decision", nasogastric tube or IV catheter can also appear if prescribed properly.

Intraoperative training consisted of a competency-based curriculum for laparoscopic appendectomy (LAPP) on a virtual reality (VR) simulator, the LapSim® (Surgical Science, Göteborg, Sweden). This curriculum was composed of seven basic tasks at different levels of difficulty and a full LAPP with previously demonstrated validity evidence and significant learning curves [13]. Each trainee had to reach proficiency twice for measures that demonstrated validity evidence, during two distinct sessions at least one hour apart during the same day to train on the next step: the seven basic tasks were to be done at the easy and then the medium level; then, the lifting and grasping task and the clipping task were performed at the difficult level; finally, the full LAPP was assessed both on the time taken and performance score.

Finally, trainees reviewed two VP after LAPP, one with uneventful and the other with complicated outcomes (i.e. post-operative intra-abdominal abscess). The environment was the same as for preoperative VP. The aim was to identify the patient's post-operative progression and initiate an appropriate evidence-based management plan [20].

Trainees

All junior residents of the department were trained in a care pathway approach. Whilst they were not usually primary operators during emergency surgery, they had responsibility for patients' perioperative management on the surgical ward, in accordance with the senior surgeon. Namely, residents managed the ward on their own and they prescribed adequate medications (analgesia, antiemetics…), dietary prescriptions and mobilization, as well as discontinuation of IV fluids, etc. A consultant round was performed ad hoc as required, but the primary responsibility for the daily ward round lied with the resident.

Before entering the study, all residents gave informed consent and completed a questionnaire about their seniority and surgical experience. Each session lasted one hour and consisted of training on one preoperative VP, one step of the intraoperative curriculum, and one post-operative VP. Two sessions per day were performed. Training was completed when correct management was achieved for all VP, and proficiency goals were reached twice at every step of the competency-based curriculum. All residents gave informed consent.

Definitions

Fever was defined as an elevation of temperature over 37.3°C, according to the Alvarado score [15]. Leukocytosis was defined as $> 10{,}000$ /mm^3. Conversion to open surgery was defined as any unplanned incision or a planned incision longer than 6 cm. Appropriate duration of antibiotics was defined as pre- or intraoperative, and no post-operative antibiotics in case of non-perforated appendix, and 3 to 5 days of post-operative antibiotics in case of perforation [20, 21]. Mortality was defined as death occurring in the hospital or within 30 days. Post-operative morbidity was defined as complications occurring in the hospital or within 30 days after surgery. Major complications were defined as those requiring surgical, radiological or endoscopic intervention (Dindo III), life-threatening complications requiring intensive care management (Dindo IV) and death (Dindo V) [17].

Statistical analysis

The quantitative data were reported as the medians and range. Normally distributed quantitative data were analysed with Student's t test, and the Mann–Whitney test was used otherwise. The qualitative data were reported as the number of patients (percentage of patients) and were compared using the Pearson's χ^2 test or the Fisher's exact test, as appropriate. The tests were always two-sided, and the level of statistical significance was set at $p < 0.05$. As this study was the first of its kind, data were lacking to formulate formal power calculations to determine the number of included patients; therefore, a convenience sample was chosen. The analysis was performed using the Statistical Package for the Social Sciences software (SPSS, version 20, Chicago, IL, USA).

Results

Five residents were enrolled, ranging from PGY 2 to 4. They were three women and two men, aged 27 (26–32). All had performed fewer than 10 LAPP as primary operator, and three had performed none. Four residents had performed fewer than five open appendectomies, and one had performed between 5 and 10. Finally, three residents had performed no laparoscopic procedures as primary operator, and two had operated between 10 and 20 laparoscopic cases. Preoperative data of pre-training and post-training patients are reported in Table 1. Demographic data and clinical presentations were comparable between groups, and preoperative management did not differ after the training.

Intraoperative data were comparable between pre-training and post-training patients (Table 2). Laparoscopy was performed in 37 patients (97.4%) with a conversion rate of 5.3%. The appendix was mostly inflamed (20 patients, 52.6%) but found to be normal in six patients (15.8%). In the latter case, it was removed in two patients (33.3%). In the other four patients, another diagnosis was made intraoperatively (1 terminal ileitis, 1 tubo-ovarian abscess, 1 retrograde menstruation and 1 free fluid of unknown origin). Abscess only occurred as a subset of the patients with perforated appendix. Procedures were performed by senior residents in all patients except one in the post-training group, who was operated by a junior resident enrolled in the study. Trainees were primary assistants

Table 1 Preoperative data of 38 patients undergoing appendectomy before (pre-training group) and after (post-training group) pathway care training of residents

	Pre-training group, n = 21	Post-training group, n = 17	P
Age (years)	27 (17–68)	25 (16–48)	0.64
Gender: male, n (%)	12 (57)	7 (41)	0.33
ASA score (1–4)	1 (1–3)	1 (1–2)	0.71
Alvarado score (0–10)	8 (4–10)	9 (4–10)	0.68
Rebound, n (%)	18 (86)	11 (65)	0.25
Fever, n (%)	10 (48)	5 (29)	0.33
Hyperleukocytosis, n (%)	17 (81)	12 (81)	0.71
Time to see the resident (min)	180 (70–445)	187 (110–450)	0.71
Time to get antibiotics (h)	11 (1–23)	11 (4–26)	0.89
Clinical diagnosis only, n (%)	12 (57)	7 (41)	0.33
US scan, n (%)	7 (33)	8 (47)	0.51
Time to get US scan (h)	8 (5–13)	10 (4–23)	0.27
CT scan, n (%)	2 (10)	2 (12)	1
Time to get CT scan (h)	13 (9–16)	19 (9–29)	0.67

ASA American Society of Anesthesiology, *US* Ultrasound, *CT* computed tomography. The data are reported as the median and range

Table 2 Intraoperative data of 38 patients undergoing appendectomy before (pre-training group) and after (post-training group) pathway care training of residents

	Pre-training group, n = 21	Post-training group, n = 17	P
Time to operation (h)	20 (7–58)	20 (4–35)	0.96
Laparoscopy, n (%)	21 (100)	16 (94)	0.45
Conversion into open surgery, n (%)	2 (10)	0 (0)	0.49
Rate of difficulty (1–5)	3 (1–5)	3 (1–4)	0.97
Operative time (min)	60 (45–135)	60 (30–150)	0.50
Inflamed appendix, n (%)	12 (57)	8 (47)	0.75
Perforated appendix, n (%)	5 (24)	6 (35)	0.49
Abscess, n (%)	3 (14)	4 (24)	0.68
Normal appendix, n (%)	3 (14)	3 (18)	1
Other diagnosis, n (%)	3 (14)	1 (6)	0.61
Intraoperative complication, n (%)	1 (5)	0 (0)	1

The data are reported as the median and range

otherwise: enrolling in the study did not help junior trainees participate more actively in the OR. Therefore, OSATS self-rating was not used, as primary operators had not been trained in the present CPA.

Post-operative data are reported in Table 3. Times to liquid [7 h (2–20) vs. 4 (4–6); P = 0.004] and solid diet [17 h (4–48) vs. 6 (4–24); P = 0.005] were significantly reduced after training. There were no significant differences in terms of post-operative pain [1 (0–3) vs. 0 (0–2); P = 0.07] and complications [4 (19%) vs. 0 (0); P = 0.11]. There were no major complications. Length of stay was not modified [48 h (30–264) vs. 44 (21–145); P = 0.22]. Finally, no patients were readmitted or reoperated within 30 days.

Discussion

This study implemented a simulation-based CPA to training in abdominal surgery, combining VP with a competency-based curriculum on a VR simulator. We chose a common disease requiring essential skills: acute

Table 3 Post-operative data of 38 patients undergoing appendectomy before (pre-training group) and after (post-training group) pathway care training of residents

	Pre-training group, *n* = 21	Post-training group, *n* = 17	*P*
Appropriate duration of antibiotics, *n* (%)	18 (86)	17 (100)	0.24
Time to liquid diet (h)	7 (2–20)	4 (4–6)	0.004
Time to solid diet (h)	17 (4–48)	6 (4–24)	0.005
Post-operative pain (0–10)	1 (0–3)	0 (0–2)	0.07
IV analgesics at Day 1[a]	5 (25)	0 (0)	0.13
Oral analgesics at Day 1[a]	11 (55)	11 (85)	0.13
Complications, *n* (%)	4 (19)	0 (0)	0.11
Major complications°, *n* (%)	0 (0)	0 (0)	ns
GI complications, *n* (%)	4 (19)	0 (0)	0.11
Length of stay (h)	48 (30–264)	44 (21–145)	0.22
Appendicitis on histology, *n* (%)	16 (76)	10 (59)	0.37

IV intravenous, *GI* gastrointestinal. The data are reported as the median and range

[a]Based on available charts, i.e. 20 in the pretraining and 13 in the post-training group, i.e. complications graded Dindo III, IV, V

appendicitis. All junior residents of our department of digestive surgery were trained. Even if the number of trainees was low (5), the purpose—to train all the junior residents of the department—was achieved. The training did not have any impact on junior residents' participation in the OR but improved patients management in the surgical ward in terms of earlier oral intake, solid and liquid. Beyond these clinical results of limited value, this study shows that such CPA to training is feasible. Moreover, there was an encouraging impact on patients' outcomes as a pilot study: indeed, there were no changes in the appendectomy pathway at St Mary's Hospital during the study, and earlier intake was only attributable to CPA.

Lectures have traditionally been used for non-technical skills training. Recently, blended learning has spread, combining traditional courses with e-learning to improve interaction and problem-based learning [22]. In their review, Rowe et al. found that blended learning had shown interesting results for healthcare students, especially in "improv(ing) a range of selected clinical competencies amongst students". However, most studies had methodological flaws and their average quality was low [23]. Moreover, blended learning is not structured in a pathway care manner and has not been designed in an immersive way with care of simulated patients, whether virtual or actors. CPA training is therefore an additional, immersive training, which has not been designed to replace blended learning or classical companionship, but to complete them.

Several fields of research have been developed to design immersive training models for non-technical skills: teamwork training in the simulated OR for intraoperative care [24, 25], simulated ward training and VP for perioperative care [9–12, 26, 27]. However, these intra- and perioperative trainings have always been performed apart from each other. Most publications assessing "combined" training have combined technical skills training and formal lectures on intraoperative care [28–30]. This study is, therefore, an innovative educational model, combining perioperative decision-making and intraoperative technical skills training in a structured care pathway manner.

Both simulated ward and VP have showed effectiveness on junior trainees [12, 31]. The simulated ward is highly immersive, using actors that can perfectly mimic patients' examination within an environment that looks very much like a real surgical ward [9, 10]. Moreover, it is associated with a simulation-based curriculum [32] and a discriminant assessment tool [33]. However, the simulated ward is expensive and presents both access issues and time constraints. In contrast, VP is free for end-users and easily accessible for everyone from a personal computer and hence easily disseminated to large groups [34]**.** VP is therefore an attractive tool for training in non-technical skills, and a growing number of academic institutions are exploring this field [35–37]. Our design of VP did not aim to assess residents explicitly; the primary intention was to train them through a simulation-based curriculum [13]. Indeed, it did not appear relevant to assess trainees with VP, whilst comments were provided through case progression. Hence, the educational value of VP was measured by their impact on patients' outcomes, which was positive.

Simulation has already demonstrated its positive impact for laparoscopic basic skills in the OR [4–7]**.** A major advance in technical skills training was the implementation of competency-based curricula on VR simulators, using proficiency goals based on discriminant measures [38, 39]. One of these curricula was designed on the LapSim®, a

VR simulator that provides a virtual laparoscopic appendectomy [13]. Indeed, laparoscopic appendectomy has shown a learning curve for technical skills [19], and residents' participation appeared to be an independent risk factor for major post-operative complications after appendectomy [40]. However, such a curriculum aims to train only in technical skills, and the purpose of our pathway approach was to train also in non-technical skills through pre- and post-operative care. In the present study, training on technical skills did not improve junior residents' participation in the OR. Hence, OSATS rating was not relevant in the present study. This finding shows that trainees' participation as primary operator not only depends on their own skills but also relies on their seniors' ability and confidence. Training outside of the OR seems all the more crucial in a setting where opportunities to be primary operator as a junior resident are scarce.

Whilst training independently on either a VR simulator or VP had demonstrated its positive impact on trainees' technical and non-technical skills [4–7, 31], the present CPA still needed to be implemented on real patients to demonstrate its educational value. This was done in the present study, both confirming the feasibility of such training and showing its positive impact on patients' management. However, given the results on oral intake only, advantages of CPA over simple instructions (e.g. trainees being told that early feeding is okay) could be discussed. First, CPA training comprised not only instructions on the post-operative management but immersive situations through the whole pathway care: some impacts of such training may not have been found due to the small sample size of both residents and patients. Second, simulation-based training has shown to be associated with retention of skills over time, whilst simple instructions may have to be given over and over [41].

A CPA to training in emergency abdominal surgery has been implemented for acute appendicitis. It both demonstrated its feasibility in a surgical department, and its positive impact on patients' management in terms of oral intake. Forthcoming studies should focus on more complex surgery, where intraoperative skills, strategy and decision-making are paramount. It could also be designed for non-surgical care. Finally, this type of training could be applied to new pathways of care, especially in the field of enhanced recovery.

Compliance with ethical standards

Conflict of interest Rajesh Aggarwal is funded by a Clinical Scientist Award from the National Institute of Health Research, U.K. (Award Grant Number NIHR/CS/009/001), and a consultant for Applied Medical. This study was approved by the NRES Committee, London.

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