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Advanced Training in Laparoscopic Abdominal Surgery (Atlas): A Systematic Review

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Abstract

Background—Simulation has widely spread this last decade, especially in laparoscopic surgery, and training out of the operating room (OR) has proven its positive impact on basic skills during real laparoscopic procedures. However, few articles dealing with advanced training in laparoscopic abdominal surgery (ATLAS) have been published so far. Such training may reduce learning curves in the OR for junior surgeons with limited access to complex laparoscopic procedures as a primary operator.

Methods—Two reviewers, using MEDLINE, EMBASE, and The Cochrane Library, conducted a systematic research with combinations of the following keywords: (teaching OR education OR computer simulation) AND laparoscopy AND (gastric OR stomach OR colorectal OR colon OR rectum OR small bowel OR liver OR spleen OR pancreas OR advanced surgery OR advanced procedure OR complex procedure). Additional studies were searched in the reference lists of all included articles.

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Results—Fifty-four original studies were retrieved. Their level of evidence was low: most of the studies were case series, one fifth purely descriptive, and there were 8 randomized trials. Porcine models and video trainers, as well as gastric and colorectal procedures were mainly assessed. The retrieved studies showed some encouraging trends in terms of trainees' satisfaction, improvement after training (but mainly on the training tool itself). Some tools have been proven to be construct-valid.

Conclusions—Higher quality studies are required to appraise ATLAS educational value.

Keywords

Education; Simulation; Surgery; Advanced Surgery; Complex Procedure

Introduction

Surgical training out of the operating room (OR) using simulation has widely spread this last decade, especially in laparoscopic surgery.^{1, 2} Training models may be inanimate such as video trainers (VT), virtual reality (VR) and augmented reality (AR) simulators, as well as live animals or cadavers. Many studies have assessed simulation for basic laparoscopic skills (such as basic drills, laparoscopic cholecystectomy and appendectomy),^{3, 4} and training out of the OR has proven its positive impact on basic skills during real laparoscopic procedures in patients.⁵⁻⁸

A further step in laparoscopic simulation is to train surgeons in complex procedures requiring more advanced technical skills, such as gastric and colorectal procedures, splenectomy, hepatectomy, pancreatectomy, adrenalectomy or small bowel anastomoses.⁹ The aim of such training is to reduce learning curves and provide safe implementation during real operations in the OR for junior surgeons who have limited access to advanced laparoscopic procedures as a primary operator.

However, few articles dealing with training in advanced laparoscopic skills have been published so far, and only one study assessed the impact of advanced training in laparoscopic abdominal surgery (ATLAS) in the OR.¹⁰ Furthermore, in their systematic review of laparoscopic colorectal surgery (LCS), Miskovic *et al.* found only 6 studies assessing simulation, and no randomized controlled trials (RCT). They concluded that there was a “notable lack of available data on the educational value of simulated training in LCS”.¹¹

The aims of this systematic review were to identify and evaluate the place of ATLAS in surgical education and define ways to improve this type of training.

Methods

This review was planned, conducted, and reported in adherence to PRISMA standards of quality for reporting systematic reviews and meta-analyses.¹²

Study Identification

We sought to include all original studies dealing with simulation in ATLAS. This simulation could be used either as a training or assessment tool. We considered as advanced technical skills all procedures except those already considered as basic in literature^{9, 13} (Table 1) such as basic drills (camera navigation, peg transfer, cutting, clip applying...), suturing on a pad, and basic procedures (diagnostic laparoscopy, laparoscopic cholecystectomy, appendectomy and hernia repair). These advanced laparoscopic procedures were: gastric procedures (Nissen fundoplication, gastrectomy, bariatric procedures), colorectal procedures, small bowel procedures (anastomosis, enterotomy closure), pancreatectomy, splenectomy, hepatectomy, and adrenalectomy.

A strategy was designed (see the online Supplementary Appendix) to search MEDLINE, EMBASE, and The Cochrane Library using search terms (MeSH terms and equivalent free-text terms) for the intervention (*i.e.*, Teaching OR Education OR Computer Simulation) combined with the term “Laparoscopy” and free-text terms for the procedures (gastric OR stomach OR colorectal OR colon OR rectum OR small bowel OR liver OR spleen OR pancreas OR advanced surgery OR advanced procedure OR complex procedure). No beginning date cutoff was used, and the last date of search was July 18, 2012. Additional studies were searched in the reference lists of all included articles.

Exclusion criteria

Editorial letters, reviews, guidelines, technical notes, and non-English-language publications were excluded. Studies assessing the impact of basic-skills training by an advanced procedure performed in a real-life situation (OR) were also excluded.

Study Selection

Two reviewers (L.B. and V.P.) independently screened all titles, and selected studies based on titles and/or abstracts. Studies that met the defined inclusion criteria were selected for article review. If it was not clear from the abstract whether a study fulfilled the inclusion criteria, the full article was reviewed independently and in duplicate. Any discrepancies between the two reviewers were resolved by consensus.

Data extraction

The following data were extracted: type of training model used for simulation, *i.e.* VT, VR or AR simulators, animals (porcine or others), cadavers; type of advanced procedure evaluated, *i.e.* gastric, colorectal, or small bowel procedures, pancreatectomy, splenectomy, hepatectomy, or adrenalectomy; type of study, *i.e.* RCT, non-randomized controlled trial, single-group pre-/post-test, case series assessing any outcome or being only descriptive; purpose(s) of the study, *i.e.* training or assessment, model description (*i.e.* description of either a procedure on a tool or a whole course), satisfaction of trainees, construct validity of a model, transfer of skills and learning curve.

According to standard definitions,¹⁴ the qualities of different training models were assessed for each procedure. These qualities were fidelity, content, construct, predictive and concurrent validity, reliability, and training ability. Training ability referred to any kind of

impact of ATLAS, whether it assessed progression on the simulation device itself (pre- and post-test), transfer of technical skills, or impact on practice.

It was judged that no data were suitable for statistical pooling due to the heterogeneity of the results.

Assessment of methodological quality

The instructions given in the *Cochrane Handbook for Systematic Reviews of Intervention*¹⁵ and the Cochrane Hepato-Biliary Group module¹⁶ were followed. Owing to the risk overestimation of intervention effects in RCTs with inadequate methodology quality, the influence of methodological quality on the results was assessed by evaluating the reported randomization and follow-up procedures in each trial: generation of allocation sequence, allocation concealment, blinding and follow-up were examined. Because participants and trainers cannot be blinded, double blinding was not feasible, but outcome assessor blinding was feasible and trials were considered to have adequate blinding if outcome assessors were blinded. If information was not available in the publication, authors were contacted in order to assess the trial correctly. Trials were considered to be of low risk of bias if the above 4 methodological qualities were adequate.

Results

Description of Studies

We identified 1605 potentially relevant articles identified from the database research. We retrieved 235 articles for abstracts screening, and 102 articles for more detailed evaluation. From these, we identified 51 appropriate articles for systematic review and found 3 articles through the references of the retrieved articles. Finally, 54 articles were included in this review (Figure 1) involving 1030 surgical trainees and 33 nurses.

There were 8 RCTs,^{10, 17-23} 12 non-randomized controlled trials (including 7 comparing different levels of experience for construct validity),^{9, 24-34} and one single-group pre-/post-test.³⁵ Cases series were found in 35 studies. No RCT had adequate methodological quality in all 4 components and therefore could be considered to have a low risk of bias. Allocation sequence was given in all 8 studies, assessors were blinded in 5 studies, type of allocation concealment was given in 2 studies but follow-up was given in only one study: Stefanidis *et al.*¹⁹ follow-up was a retention test, performed 6 months after the initial training.

Types of Advanced Procedures

The different types of laparoscopic advanced procedures evaluated are listed in Figure 2. Simulation for gastric, colorectal, small bowel, splenic and hepatic procedures, as well as for adrenalectomy was found whereas no study assessing simulation for pancreatic surgery has been published so far. One study over five assessed multiple procedures.

Gastric procedures—Twenty-nine studies assessed simulation in gastric surgery. Whilst most procedures were Nissen fundoplication,^{19-22, 26, 32-34, 36-47} there were also bariatric procedures (either gastric banding^{29, 48, 49} or by-pass^{9, 50}), gastrointestinal

anastomoses,^{43, 51, 52} gastrectomy and seromyotomy.^{53, 54} Four of these studies were RCTs.¹⁷⁻²⁰

Twelve studies implemented gastric procedures in a laparoscopic simulator. The majority of these used VT: 7 of them used animal organs whilst 2 used synthetic models (foam stomach) and one used both. Two studies implemented VR simulators, both for laparoscopic gastric banding procedure. Sixteen studies used live animal models: most of them resorted to swine models but 4 studies involved other animals. Finally, 2 studies were conducted on cadavers.

Colorectal procedures—Twenty-two studies assessed simulation in LCS, including 2 RCTs.^{10, 18} The types of LCS assessed were a sigmoid colectomy,^{17, 18, 24-27, 30, 47, 55, 56} a right hemi-colectomy,^{10, 57} an anterior resection,⁵⁸ all 3 procedures^{43, 59-61} and colonic devascularization.⁴⁶ In 4 studies, the type of procedure was not specified.^{36, 38, 52, 62}

Ten studies implemented LCS in a simulator. The majority of them used the same AR simulator, the ProMIS™ (CAE Healthcare, Montreal, QC, Canada) for a laparoscopic sigmoid colectomy. Two studies utilized VR simulators in order to describe a right hemi-colectomy and an anterior resection. Finally, one study used VT with animal organs and involved both colorectal and gastric procedures. This study was also purely descriptive. Seven studies were conducted on animals, including 4 on porcine. Finally, 8 studies were conducted on cadavers, including one RCT assessing the transfer of skills in the OR as described below.¹⁰

Small Bowel procedures—Nine studies assessed simulation for laparoscopic small bowel surgery, including one study utilizing multiple models²³ and 4 studies assessing multiple procedures.^{42, 43, 52, 63} Six studies involved entero-enteral anastomosis,^{28, 42, 43, 51, 52, 64} 3 involved enterotomy closure,^{23, 28, 63} and one consisted in running the small bowel.³⁵ One of these studies was a RCT.²³

Six studies involved laparoscopic simulators, all being VT: 4 used animal organs, one used synthetic models and one used both. Three studies were conducted on animals. In 2 of these 3 studies, the animal model was used as an assessment tool. Stelzer *et al.* showed a positive impact of a 6-week VT training on both VT and running the small bowel in porcine,³⁵ whilst Heinrich *et al.* conducted a RCT comparing the impact in both rabbits and VT of a training in either live rabbits or rabbit gut in VT (biopsy and enterotomy closure).²³ Both groups improved but the *in vivo* assessment improved significantly only in the live rabbit group. Finally, one study involved cadavers.

Splenectomy—Simulated splenectomy was found in 8 studies, including 6 studies involving multiple procedures.^{26, 38, 43, 46, 47, 63} None of these studies were randomized. Adrales *et al.* described multiple procedures on a synthetic model in VT.⁶³ Six studies involved live animals: rats were used in 3 studies,^{26, 47, 65} porcine in 2^{38, 66} and rabbits in one.⁴⁶ Finally, one study assessed laparoscopic splenectomy training in cadavers.⁴³

Hepatic procedures—Simulated hepatic procedures were found in 2 studies. Strickland *et al.* assessed the construct validity of a liver tumorectomy in an AR simulator,³¹ whilst

Udomsawaengsup *et al.* described a training course on cadavers involving, along with other resections, a liver procedure. However, the type of procedure was not specified.⁴³

Adrenalectomy—One study described a simulated laparoscopic adrenalectomy on a porcine model.⁶⁷

Multiple procedures—As described above, 12 studies assessed multiple advanced laparoscopic procedures: 6 of them used VT,^{36, 38, 42, 51, 52, 64} 2 used cadavers,^{43, 50} 5 used porcine models^{38, 42, 52, 64, 68} and 3 used other animals.^{26, 46, 47} Most of these studies were purely descriptive, either for a model or for a training course.^{36, 43, 46, 47, 50, 51}

Types of Training Models

The different types of training models used for ATLAS and the different types of studies are listed in Figure 3. The qualities of different training models are reported Table 2. Most devices were assessed for fidelity and content validity in every procedure, but only 2 devices were assessed for all the required qualities: the ProMIS™ for laparoscopic sigmoid colectomy, and an unspecified VT with organic tissue for gastric by-pass.

Laparoscopic simulators

VT: Fifteen studies used VT to assess ATLAS: 10 studies used animal organs, 3 used synthetic models and 2 used both. Two of these studies were RCTs. The ATLAS assessed was mostly gastric surgery (10 studies) and small bowel procedures (6 studies).

Twelve studies utilized VT only as a training tool. Most consisted of model description. Three studies assessed trainees' satisfaction as well as face and content validity. The study of Palter *et al.*⁴² compared the satisfaction of residents after training for suturing on different models: the model perceived as having the best educational value was the porcine model, then the synthetic Nissen model. Two studies assessed the learning curves of anastomoses. Rodriguez *et al.* assessed learning curves for hand-sewn jejunum-jejunal (JJA) and gastro-jejunal anastomoses on VT with a plateau for operative time after 70 hours of practice.⁵² Hamad *et al.* assessed learning curve for JJA on VT with a plateau after 40 anastomoses in one surgeon.⁶⁴ Finally, the other items assessed after training on VT were the cost of a course and the impact of feedback.

Three studies used VT both as a training and assessment tool, with both pre- and post-test on the same simulator. Aggarwal *et al.*²⁸ showed that novices in laparoscopic surgery could meet some experts' benchmarks for enterotomy closure, and demonstrated both construct validity and improvement after training on an organic gastric by-pass model.⁹

AR: Eight studies resorted to AR to assess ATLAS, including 7 studies assessing LCS and one assessing a liver tumorectomy. Two studies were RCTs.^{17, 18}

Six studies involved AR simulators only as a training tool. Two studies assessed construct validity for the ProMIS™, either for laparoscopic sigmoid colectomy³⁰ or for hepatic tumorectomy.³¹ Leblanc *et al.* assessed metrics and rating scales for laparoscopic sigmoid colectomy in 4 studies: 2 randomized crossover studies^{17, 18} compared hand-assisted (HAL)

and straight laparoscopic (SL) sigmoid colectomies, and 2 other studies compared rating scales and trainees' satisfaction on ProMIST™ and cadavers.^{24, 25} Whilst satisfaction was significantly better with cadavers ($p < 0.001$), trainers rated generic ($p = 0.008$) and specific skills ($p = 0.028$) more accurately on the simulator.

Two studies used AR simulators both as a training and assessment tool. Essani *et al.* demonstrated significant improvement for time and leak rate ($p < 0.05$) after 8 weeks of training for SL sigmoid colectomy.⁵⁵ Boyle *et al.*²⁷ showed significant improvement for path length and smoothness after 5 HAL sigmoidectomies, with no difference between a group getting feedback and a control group.

VR: Four studies used VR to assess ATLAS, half of them implementing colorectal procedures and the other half gastric procedures. Three of these studies were purely descriptive whilst the latter assessed construct validity, as well as satisfaction, face and content validity for a laparoscopic gastric band VR simulator.²⁹ None were RCTs.

Live animals

Porcine: Twenty studies used porcine model to assess ATLAS. The type of procedure assessed was mostly gastric (14 cases), then colorectal (6 cases). Three studies were RCTs: they used porcine only as an assessment tool.

Fifteen studies used porcine model as a training tool. Satisfaction of trainees was assessed with good results, between 4.5 and 4.7/5,^{61, 66} and 82% to 100% of the trainees found training on porcine very helpful.^{42, 54} Three studies assessed the construct validity of rating scales and metrics during a Nissen fundoplication, and 3 studies looked at the impact of training on practice: Lin *et al.*⁶⁸ showed an increasing participation of trainees to laparoscopic colectomies without any alteration in patients' outcomes; Kinoshita *et al.*⁵⁴ found promising results for laparoscopic gastrectomy (2 thirds of the surgeons improved in terms of operative time and number of lymph nodes resected); however Heniford *et al.*⁶⁶ demonstrated a far better impact of intraoperative preceptorship compared to simulation for laparoscopic splenectomy.

Two studies used live porcine both as a training and assessment tool.^{44, 45} Both showed significant improvement after training, even after 6 months.

Five studies utilized live porcine only as an assessment tool. One study assessed a rating scale for SL sigmoid colectomy and found that trainees overestimated their own performance.⁵⁶ Four studies, including 3 RCTs, used porcine to assess transfer of skills during an advanced procedure after training in basic skills on VT. In the 3 RCTs, performance was significantly better in the intervention group compared to controls (in each case, $p < 0.001$). In the fourth study, there was no control group, but the authors found significant improvement between the pre- and the post-test ($p < 0.001$).

Other animals: Six studies used other live animals to assess ATLAS, including 4 studies in rats^{26, 47, 49, 65} and 2 studies in rabbits.^{23, 46} Half of these studies involved multiple

procedures. Again, gastric and colorectal procedures were mainly involved. One of these studies was a RCT.²³

Five studies used rats or rabbits only as training tools. Four of them were purely descriptive. In the fifth, Gutt *et al.*²⁶ assessed the impact of training on multiple advanced procedures in rats on basic technical skills in VT. Trainees were assessed before and after the course, and compared to a control group: their progression was significantly better than in the control group. One study used rabbits both as a training and assessment tool.

Cadavers—Finally, 8 studies used cadavers to assess ATLAS, including 2 studies involving multiple procedures.^{43, 50} The major type of surgery involved was colorectal. There was one RCT.

All studies involved cadavers only as a training tool. Palter *et al.* assessed for the first time the transfer of skills of ATLAS in the OR with good results, as mentioned above: training in LCS on cadavers was the last step of a whole training curriculum involving also basic skills training on a simulator and cognitive courses. Trainees were then assessed during a real right hemi-colectomy, using validated rating scales. Curricular-trained residents demonstrated higher performance in the OR ($p = 0.03$).¹⁰

The other studies assessed satisfaction of trainees: 5 assessed the model itself whilst 3 assessed a whole course; Wyles *et al.*⁶¹ compared the satisfaction of surgeons for colorectal procedures on cadavers and porcine: overall satisfaction was even, but cadavers were thought to be better for anatomy and as a training tool; as described above, Leblanc *et al.*^{24, 25} compared AR simulators and cadavers for satisfaction and rating scales^{24, 25}.

Discussion

This is the first systematic review of simulation for advanced abdominal laparoscopic surgery. Fifty-four studies were retrieved. These studies were very heterogeneous in terms of tools, type of procedures, and type of studies. The main tools used in ATLAS were porcine and VT despite very different costs (swines are far more expensive models than VT)¹ and most VT studies used animal organs, which are cheaper than synthetic models.³⁸ Gastric and colorectal procedures were mainly assessed, most of the time during a laparoscopic Nissen fundoplication and a sigmoid colectomy (either SL or HAL). The level of evidence of the retrieved studies was low. Most of the studies were case series, and one fifth was purely descriptive. There were only 8 RCTs, and none could be considered to be of low risk of bias. However, one RCT assessed the transfer of skills in the OR with good results¹⁰ and despite their relative weaknesses, the retrieved studies showed some encouraging trends, in terms of trainees' satisfaction,^{42, 52, 59, 64, 66} and improvement in advanced technical skills after training (but mainly on the training tool itself).^{9, 28, 44, 45, 55} Furthermore, some tools have been proven to be construct-valid.^{9, 29-31} However, very few studies assessed the transfer of advanced technical skills from training tools to live procedures, especially in the OR.

Is ATLAS a genuine need?

In their systematic review on mentoring and simulation in LCS, Miskovic *et al.* stated that only limited structured guidelines and few reports on dedicated programs existed for ATLAS:¹¹ only Fleshman *et al.* developed experts guidelines for education in LCS.⁶⁹ However, learning curves have been estimated as being 20 cases for Nissen fundoplication,⁷⁰ and between 30 and 60 cases in the technically challenging field of LCS.⁷¹⁻⁷³ Unfortunately, residents' experience is far from reaching these goals. In Palter *et al.* study, the majority of 14 PGY 3-5 had no experience in laparoscopic foregut and bariatric surgery as the primary operator, and 36% had performed no LCS.⁴² Rattner *et al.* interviewed 85 residents, being at least PGY 4, with similar findings: 60% had performed 3 laparoscopic Nissen funduplications, 81% had performed 3 LCS, and 86% had done 3 laparoscopic splenectomies.⁷⁴ This gap between expected level and actual practice has prompted Essani *et al.*⁵⁵ to write that “the adequacy of Dr. Halsted's one-century-old apprenticeship model is questionable in LCS”, and to promote the use of ATLAS. Training out of the OR may indeed reduce learning curves and favor a safe implementation of advanced procedures. Moreover, Lin *et al.*⁶⁸ found that ATLAS favored residents' participation in the OR without altering patients' outcomes. The need for ATLAS is therefore real, and studies implementing ATLAS with higher level of evidence should be designed. Other fields of simulation, medical or otherwise, may inspire this forthcoming research.

Lessons from basic skills simulation

There is a wealth of data on simulation for basic laparoscopic skills, but many studies in basic simulation have similar flaws to studies assessing ATLAS: small sample sizes, multiple simulation models (simulators, cadavers, live animals), varying rating scales, and lacks of objective tools to assess skills acquisition.^{2, 4} ATLAS RCTs' weakness in methodological quality is also comparable to basic skills studies': among 23 RCTs, Gurusamy *et al.*³ found only 3 trials at low risk of bias. We could however debate the use of follow-up as a criterion of methodological quality in educational studies: in this field, follow-up is given mainly as a retention test, and retention test is more an outcome than a proof of quality. Some studies assessed the transfer of basic skills on VT or porcine,³ and a few studies demonstrated that training out of the OR had some positive impact on basic skills during real laparoscopic procedures in the operating room.⁵⁻⁸ In their systematic review, Sturm *et al.*⁷⁵ found 4 RCTs and one non-randomized comparative trial assessing the transfer of basic skills during a real laparoscopic cholecystectomy in the OR: groups who underwent simulation performed better in the OR, but the difference with controls was not significant in all parameters, and the authors concluded that more studies were required to strengthen the evidence of such transfer. In ATLAS, there is a lack a data concerning the transfer of advanced technical skills, especially in the OR. Only one study assessed the impact of simulation for ATLAS on technical skills during real procedures on patients (a laparoscopic right hemi-colectomy): there was a significantly better performance compared to conventionally trained residents.¹⁰ Furthermore, a major advance in basic technical skills literature was the implementation of training curricula, using proficiency goals on construct-valid measures.^{76, 77} Only the pre-cited study of Palter *et al.*¹⁰ has implemented such

training curriculum in ATLAS so far. In short, lessons learned from basic skills training are the following: ATLAS still needs studies of higher quality to assess its educational value, especially RCTs; implementation of training curricula and transfer of technical skills in the OR are the most lacking fields of research in ATLAS.

Simulated non-abdominal advanced procedures

Simulation for advanced procedures has also been implemented in other medical specialties, such as vascular surgery (with carotid artery stenting), craniofacial surgery (congenital or traumatic facial deformities), neurosurgery (brain tumors), colonoscopy (flexures and loops) or interventional radiology (radiofrequency thermal ablation).⁷⁸⁻⁸² Two leads of research that have been developed in this field could be applied to ATLAS. First, advanced procedures could be split in procedural modules (also called part-procedural tasks) to strengthen the impact of training, as a short duration of training may produce better results.³ Such procedural modules have been implemented in vascular surgery and endoscopy. Willaert *et al.*⁷⁹ demonstrated that training on a carotid stenting module was as effective as training on a full procedure, whilst Sugden *et al.*⁷⁸ developed a VR curriculum in colonoscopy, progressing from basic modules (intubating the sigmoid and descending colon) to advanced modules (intubating the splenic flexure), and then to the full procedure (a full colonoscopy). In ATLAS, a few studies set a workflow analysis with specific steps,^{32, 44} but no study has dichotomized a full procedure into modules so far. Second, training on patient-specific models could be an answer to the “ceiling effect associated with the fixed nature of the anatomy model” described by Essani *et al.*⁵⁵ whilst using an AR simulator. Patient-specific models have been implemented on various medical fields such as vascular, craniofacial or neurosurgery,⁸² whereas only the descriptive study Suzuki *et al.*⁵⁷ has resorted to patient-specific simulation in ATLAS.

Advanced simulation in non-medical fields

The main fields concerned are commercial and military aviation, space missions and sports.⁸² The first and most well-known is the aviation industry where advanced simulation on high-fidelity models has proven to be time- and cost-effective compared to real-life test flights.⁸³ In ATLAS, only one study evaluated the cost of a course,³⁸ but no study assessed ATLAS cost-effectiveness compared to standard training. There is a need for such a study which would assess the cost of the training itself, as well as the cost of care (such as operative time and patients' outcomes). Furthermore, the notion of strategy is very present in non-medical advanced simulation, especially in the military field: fighter pilots train on navigation, targeting, flight paths, but also on evaluation of strategic plans.⁸⁴ The complexity of advanced procedures in ATLAS also requires strategy, raising the question of feasibility for deliberate practice. In the present review, only 2 studies assessed the impact of feedback in ATLAS with conflicting results: Bergamashi *et al.*²⁰ found better results only for accuracy error in the feedback group ($p = 0.01$), whereas Boyle *et al.*²⁷ found better path length ($p = 0.01$) and smoothness ($p = 0.045$) in the control group. However, no study assessed deliberate practice for ATLAS. Moreover, strategy implies knowledge and decision-making whereas ATLAS is almost only about technical skills.

Future initiatives for ATLAS

Looking at the other fields of simulation helps to appraise forthcoming research in ATLAS. The main leads are the design of training curricula and the assessment of ATLAS educational value. There is a need for a competency-based curricular approach in ATLAS, using simulation to train on both technical and non-technical skills. Technical skills curricula should use construct-valid metrics and include part-procedural tasks and full procedures, based on the basic skills and endoscopic experience.⁷⁶⁻⁷⁸ Non-technical skills should imply cognitive training (such as knowledge and decision making) and teamwork. Such a global approach would provide the full pathway care training that a complex procedure requires. Moreover, curricula's impact should be assessed both on technical skills in the OR and on the quality of care. Other fields of research could assess the impact of deliberate practice in ATLAS or design patient-specific models in VR, to overcome the fixed nature of the simulated procedures.⁵⁵

Conclusion

Simulation in advanced laparoscopic surgery is needed, but only 54 studies addressed the question of ATLAS with a generally poor level of evidence. Higher quality studies, and especially RCTs are still awaited to appraise ATLAS educational value. Forthcoming studies should assess the following: transfer of advanced technical skills in the OR, and construct validity for models and metrics, in order to build training curricula. Other leads to improve ATLAS may be the design of patient-specific models, the assessment of deliberate practice, and the development of a pathway care approach involving both technical and non-technical skills.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1.
Study Flow for Advanced Training in Laparoscopic Abdominal Surgery (ATLAS).

Figure 2.
Types of implemented procedures in advanced laparoscopic surgery simulation. VT = video trainer; VR = virtual reality simulator; AR = Augmented reality simulator.

Figure 3.

Types of implemented models in advanced laparoscopic surgery simulation (only main groups of studies are reported in this diagram).

VT = video trainer; VR = virtual reality simulator; AR = augmented reality simulator; TS = transfer of skills; Pre/post test: training and pre- and post-assessment. * VT training is basic skills in these 4 studies.

Table 1

Definition of basic and advanced laparoscopic procedures.

Basic laparoscopic procedures	Advanced laparoscopic procedures
Diagnostic laparoscopy	Gastric procedures (fundoplication, bariatric procedures, gastrectomy)
Cholecystectomy	Colorectal procedures
Appendectomy	Small bowel procedures (anastomosis, enterotomy closure)
Hernia repair	Pancreatectomy
	Splenectomy
	Hepatectomy
	Adrenalectomy

Table 2

Qualities of simulation devices in ATLAS.

Procedures	Simulation Devices	Fidelity	Validity			Reliability	Training Ability
			Content	Construct	Predictive Concurrent		
Gastric Nissen fundoplication	VT						
	- Organ						
	• Tuebinger MIC-trainer ³⁶	X					
	• NS ^{37,37, 39-41}	X	X				
	- Synthetic						
	• FLS ⁴²	X	X		X	X	
	• Pelvic trainer (USSC, Norwalk, CT, USA) ²⁰						
	• NS ⁴¹	X	X				
	Porcine ^{19,21,22,32,34,44,45}	X		X		X	X
	Other live animals						
Gastric banding	- Rabbits ⁴⁶	X					
	- Rats ^{26,73}	X					X
	Human cadavers ⁴³	X	X				
	VR PHANToM Omni haptic interface devices (Sensable Technologies, Inc., Boston, MA) ^{29,48}	X	X	X			
	Other live animals						
	- Rats ⁴⁹	X					
	VT						
	- Organ NS ⁹	X	X	X	X	X	X
	Human cadavers ⁵⁰	X	X				
	VT						
Gastro-intestinal anastomosis	- Organ						
	• Pier Götz trainer (MEDING GmbH, D-5138 Oberbruch) ⁵¹	X					
	• Endotrainer ⁵²	X					X
	Human cadavers ⁴³	X	X				
	Porcine ⁵⁴	X	X				X
Gastrectomy							

Procedures	Simulation Devices	Fidelity	Validity			Reliability	Training Ability
			Content	Construct	Predictive Concurrent		
Seromyotomy Colorectal Sigmoidectomy	Porcine ⁵³	X					
	AR ProMIST™ (CAE, Toronto, Ontario) ^{17,18,24,25,27,30,55}	X	X	X	X	X	X
	Porcine ⁵⁶					X	
	Other live animals						
	- Rats ^{26,47}	X					X
	Human cadavers ^{24,25,43,50,59-61}	X	X		X	X	
	VR PHANToM Omni haptic interface devices (Sensable Technologies, Inc., Boston,MA) ⁵⁷	X					
	Human cadavers ^{10,43,50,59-61}	X	X				X
	VR PHANToM Omni haptic interface devices (Sensable Technologies, Inc., Boston,MA) ⁵⁸	X					
	Human cadavers ^{43,59-61}	X	X				
Anterior resection Colonic devascularization NS	Other live animals						
	- Rabbits ⁴⁶	X					
	VT						
	- Organ						
	• Tuebinger MIC-trainer ³⁶	X					
	• NS ³⁸	X					
	Porcine ⁵²						X
	Human cadavers ⁶²	X					
	VT						
	- Organ						
Small Bowel Jejuno-jejunal anastomosis	• Pier/Götz trainer (MEDING GmbH, D-5138 Oberbruch) ⁵¹	X					
	• Endotrainer ⁵²	X					
	• Limbs & Things Ltd, Bristol,England ⁶⁴						X
	• NS ²⁸			X			X
	- Synthetic NS ²⁸			X			X
	Porcine ⁴²	X	X				
	Human cadavers ⁴³	X	X				

Procedures	Simulation Devices	Fidelity	Validity		Predictive Concurrent	Reliability	Training Ability
Enterotomy closure	VT						
	- Organ						
	• Limbs & Things Ltd, Bristol,England ⁶⁴						X
	• NS ^{23,28}		X		X	X	X
	- Synthetic						
Running	• NS ²⁸						X
	• University of Kentucky laparoscopic models ⁶³		X			X	X
	Other live animals				X	X	X
	- Rabbits ²³				X	X	X
	Porcine ³⁵				X	X	
Splenectomy	VT	X					
	- Synthetic University of Kentucky laparoscopic models ⁶³	X					X
	Porcine ^{38,66}	X		X			
	Other live animals						
	- Rats ^{26,47,65}	X					X
Hepatic Tumorectomy NS	- Rabbits ⁴⁶	X					
	Human cadavers Thiel cadavers ⁴³	X		X			
	AR ProMIS™ (CAE, Toronto, Ontario) ³¹		X				
	Human cadavers ⁴³	X					
	Porcine ⁶⁷	X					

VT: Video Trainers, VR: Virtual Reality simulators, AR: Augmented Reality simulators, NS: Not Specified, FLS: Fundamentals of Laparoscopic Surgery.