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THE TRANSITION FROM VIRTUAL REALITY TO REAL VIRTUALITY: ADVANCED IMAGING AND SIMULATION IN GENERAL SURGERY

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Abstract – *Individual anatomical variations, involvement of organs in neoplastic lesions and consequent preoperative planning are some issues that surgeons have to face every day in their clinical activity. The use of dedicated softwares, together with tools for patient-tailored training, is likely to improve clinical outcomes and patients' safety. We decided to review the literature to report the current role of virtual reality and simulation in general surgery.*

A search was systematically performed on Pubmed, EMbase, Cochrane Library and Up ToDate databases. The search was limited to articles written in English from January 2005 through June 2016. Altogether, 1,038 articles were found using this search strategy.

All studies, case series and reports in the medical field pertaining to preoperative planning, VR and Augmented Reality (AR) application in general surgery that provided translational data were considered eligible to be included. Two authors independently screened the articles by title, abstract and keywords, and then selected 7 papers to be included in this review (4 for VR, 2 for AR and 1 for preoperative planning).

Virtual reality training appears to decrease the operating time and improve the operative performance of surgical trainees with limited laparoscopic experience when compared with no training or with box-trainer training. The ability of virtual reality tools to guide surgeons during complex procedures represents a revolution for increased safety and overcoming minimally invasive surgery-related limitations.

KEYWORDS: *Virtual reality, Preoperative planning, 3D reconstruction, Augmented reality, Patient safety, Surgical education.*

OBJECTIVE

Innovation and simplification. Those two words represent the synthesis of the present direction of surgical research. Or, at least, represent what the direction should be. There is no reason to keep medicine and surgery out of the process of modernization and digitalization that we are going through thanks to the widespread application of virtual reality in our lives.

After a century of Surgery, digital technologies dramatically changed our lives and daily activities, but are still under-estimated in the field of medicine. Individual anatomical variations, involvement of organs in neoplastic lesions and consequent preoperative planning are some issues that surge-

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ons have to face every day in the clinical activity. The use of dedicated softwares, together with tools for patient-tailored training, is likely to improve clinical outcomes and patients' safety.

Virtual reality (VR) recently appeared in our lives. It is a digital transposition of real objects and settings through a computer: it can be defined "immersive" or "non-immersive", depending if you are experiencing a complete interaction with the virtual setting or not. All the senses should be supported in order to get a completely immersive experience, included orientation. VR is now largely diffused in other fields like aeronautic training, video games and commercial purposes. Immersive virtual reality tools like "Oculus" will be soon available for everyone, making real the dream of a "real virtuality", i.e. the complete integration of real life and virtual data. Where are we now with the application of such innovations in surgery? Is still acceptable to propose the classical "see-one, do-one, teach-one" model of knowledge transmission in surgery? Shouldn't we guarantee the best preoperative planning possible to our patients? Can we increase patient safety and cost-effectiveness of the surgical learning curve for residents and young surgeons?

Therefore, we decided to review the literature of the last ten years in order to report the state of the art of virtual reality and 3D rendering tools in general surgery, in terms of preoperative planning, intraoperative augmented reality, and virtual reality.

DATA SOURCES AND REVIEW METHODS

A search was systematically performed on Pubmed, EMbase, Cochrane Library and Up ToDate databases by entering the strings: "preoperative 3D planning" (or "preoperative planning"; or "preoperative reconstruction"; or "3D reconstruction") AND "general surgery" (or "surgery"); "augmented reality" AND "general surgery" (or "surgery"); "virtual reality" AND "general surgery" (or "surgery"). Unpublished reports were not considered eligible. The search was limited to articles written in English from January 2005 through June 2016. Altogether, 1,038 articles were found using this search strategy. The complete article was retrieved when the information in the title or abstract appeared to meet the objective of this review. Also, the reference lists of the studies thus obtained were searched manually for any relevant articles not found in the computerized search.

All studies, case series and reports in the medical field about the preoperative planning, VR and Augmented Reality (AR) application in general surgery that provided translational data were considered eligible to be included. Two authors (PM and GS) independently screened the articles by title, abstract and key words, and then selected 7 papers to be included in this review (4 for VR, 2 for AR and 1 for preoperative planning). Any disagreement was resolved by discussion or with the opinion of the senior authors (GR, FDB, and AF).

VR AND SIMULATION

Table I summarizes the characteristics of the papers included in this review that provided data on VR-based simulation outcomes.

In their study published in 2007, Aggarwal et al[1] recruited 30 participants; 10 were experienced laparoscopic surgeons and 20 were novice surgeons. The 20 novice laparoscopic surgeons were randomly allocated to either control or VR training groups using the closed envelope technique. Intergroup comparisons revealed significant differences in performance on the first laparoscopic cholecystectomy between control and VR-trained groups in terms of time taken (4590 *vs.* 2165 seconds, p=0.038), total path length (169 *vs.* 87 meters, p=0.001), total number of movements (2446 *vs.* 1029, p=0.009), and video rating scores 17 *vs.* 25 (out of 35), p=0.001. Statistical equivalence of performance was achieved between the fifth laparoscopic cholecystectomy for the control group and the third for the VR-trained group on dexterity-based parameters: time taken (1598 *vs.* 1365 seconds, p=0.131), total path length (86 *vs.* 49 meters, p=0.110), total number of movements (875 *vs.* 647, p=0.110), although video rating scores (out of 35) remained significantly different in favor of the VR-trained group (25 *vs.* 31, p=0.003)[1].

In the study published by Botden et al[2] in 2008, 45 participants were randomly and blinded divided into two equally sized groups: group A started with a training session on the traditional box trainer for half an hour followed by a session on the SimSurgery VR simulator for half an hour; group B started with the same session on the SimSurgery VR simulator, followed by the session on the traditional box trainer. After finishing the training sessions, all participants (N = 45) were asked to fill out a questionnaire regarding their opinion on the simulators used in the study and their role in laparoscopic suturing training. No statistically significant differences were demonstrated between group A and B. However, participants' opinions showed that the traditional box trainer scored higher on all aspects than the SimSurgery VR laparoscopic simulator

TABLE 1. VR-based surgical simulation studies.

Author	*Year*	*Population*	*MI approach*	*Study design*
Aggarwal et al[1]	2007	19	Laparoscopic	10 were experienced laparoscopic surgeons and 20 were novice surgeons. The 20 novice laparoscopic surgeons were randomly allocated to either control or VR training groups using the closed envelope technique
Botden et al[2]	2008	45	Laparoscopic	45 participants were randomly and blinded divided into two equally sized groups: group A started with a training session on the traditional box trainer for half an hour followed by a session on the SimSurgery VR simulator for half an hour; group B started with the same session on the SimSurgery VR simulator, followed by the session on the traditional box trainer.
Araujo et al[3]	2014	14	Laparoscopic	7 trainees completed a 2-h VR simulator training in the laparoscopic sigmoid colectomy module (study group). The remaining 7 surgeons (control group) underwent no intervention. On the same day, all participants performed a sigmoid colectomy with anastomosis on a pig.
Nickel et al[4]	2015	84	Laparoscopic	Laparoscopy-naıve medical students were randomized in 2 groups stratified for sex. The BL group (n¼42) used E-learning for laparoscopic cholecystectomy (LC) and practiced basic skills with box trainers. The VR group (n¼42) trained basic skills and LC on the LAP Mentor II

(p=0.001). In particular, for the VR simulator the features 'haptic sensations of the tissue' and 'resistance of needle and thread' were regarded as 'absolutely unrealistic' by 41.5% and 48.8% of the participants, respectively. On these same features the traditional box trainer was rated as 'good' by 29.8% and 42.2%, respectively, and 'excellent' by 33.3% and 35.6%, respectively[2].

In 2014, Araujo et al[3], in a randomized and single-blinded study, assigned 14 residents naïve to laparoscopic surgery in block to two groups. Seven trainees completed a 2-h VR simulator training in the laparoscopic sigmoid colectomy module (study group). The remaining seven surgeons (control group) underwent no intervention. On the same day, all participants performed a sigmoid colectomy with anastomosis on a pig. In the control group, the mean score for generic skills was 17.2 (16.5-18). In the study group, it was 20.1 (16.5-22) (p=0.002). Regarding specific skills, the mean score was 20.2 (19-21.5) in the control group and 24.2 (21-27.5) in the study group (p=0.001) [3].

Recently, Nickel et al[4] reported an interesting study, designed as a prospective monocentric, 2-arm, randomized trial with 2 active intervention groups, virtual reality (VR) *vs.* blended learning (BL). The VR and BL groups were compared for the effectiveness of training a basic operation in laparoscopic surgery. Each group employed their training method (LAP-mentor II (Symbionix) for VR or e-learning and box trainer for BL) for gaining laparoscopic skills. The training consisted of 3 sessions of 4 hours, adding to a total training time of 12 hours per participant in each group. After completing the training, the students participated in a post-test consisting of a knowledge test and a simulated operation on a cadaver model. The results show that the average operation time was significantly shorter for the VR group with 75.8 ± 7.1 min compared with the BL group with 77.6 ± 7.0 min (p=0.03). The BL group completed 9 operations compared with 19 in the VR group (21% *vs.* 45% completed operations, p=0.02). In contrast, the score of the knowledge test about LC was significantly better for the BL group than for the VR group (13.3 ± 1.3 *vs.* 11.0 ± 1.7 out of 16 total points; p<0.001)[4].

PREOPERATIVE PLANNING

In a paper published in 2010, Chen et al[5] described their experience with the use of virtual reality for the functional evaluation of the liver before surgery. From May 2006 to December 2008 they evaluated 42 patients (33 men and 9 women) with liver cancer, and with the use of a 3D visional and reconstructive software they obtained a 3D image from the CT scan. Thirty-eight patients (90.5%) ultimately underwent hepatic resection, while four patients (9.5%) were excluded from resection due to the inadequate liver volume of remnant liver, results of the liver biopsy and other medical factors. The authors reported no significant difference (p>0.05) between preoperatively calculated volumes of virtual resection part (424-1267 ml) and actual volumes of resected specimen's weight (429-1198 g) in all 38 hepatic resections.

In addition to virtual reality, several tools are available for preoperative planning, and image fusion is one of the most promising. Medical image fusion (IF) can be defined as overlaying of images from the same or different imaging modalities[6]. Software for fusion of real-time ultrasound images with CT, MRI, or PET/CT is incorporated in several high-end ultrasound systems, but also static ultrasound images can be used. IF is not of everyday use up-to-now, but thanks to its ductility it is quickly expanding the indications and the fields of application. Studies have been reported of IF application for breast, liver, prostate and brain[6]. Indeed, the study of solid organs may benefit such an approach, due to the complexity of reporting the three-dimensional structure on a bidimensional plane. Murakami et al[7] reported their experience with 3D-PET/CT fusion for liver and pancreas, which provides both anatomical and functional information. According to the authors, thanks to these images the positional relationships among blood vessels, organs, and tumors are showed more clearly. However, the authors state that images obtained with this technique are more likely to be useful as a map for minimally invasive surgical and endoscopic procedures, rather than be part of the diagnostic process.

AUGMENTED REALITY

Lots of manuscripts in literature report description of AR systems but actual applications of this tool are hard to be found. Recently, Pessaux et al[8] reported a case of Robotic duodenopancreatectomy assisted with augmented reality and real-time fluorescence guidance. The authors reported their experience along with a detailed description of technical issues regarding 3D rendering and virtual model generation[8]. The patient was a 77-years old female affected by recurrent pancreatitis due to an IPMN. According to the authors, AR and fluorescence allowed for precise and safe recognition of all the important vascular and biliary structures. The operative time resulted to be 360 min, and the post-operative course was uneventful.

From the same research group, Hallet et al[9] in 2015 reported their experience with AR-guided trans-thoracic minimally invasive liver resection. They present the case of a 52 years-old man affected by a well-differentiated hepatocellular carcinoma (HCC) in segment 8 on a non-cirrhotic liver with non-alcoholic steatohepatitis. It is well known that the posterior and superior liver segments are more complex and challenging, in particular when approached laparoscopically. Therefore, authors[9] proposed a purely trans-thoracic minimally invasive approach through the diaphragm, since they considered it to be easier and safer. The operative time was 270 minutes, with an estimated blood loss of 300 ml and an uneventful post-operative course (the patient was discharged on post-operative day 4). In this case the use of AR helped in the trocars positioning to obtain optimal triangulation; then after gaining the access in the thoracic cavity, the AR was used to confirm and further delineate tumor localization; finally, in the abdominal cavity, AR allowed for even more precise appreciation of the tumor localization and was used to delineate resection margins.

DISCUSSION

In his interesting paper published on Nature-Clinical Practice in 2008, Grantcharov stressed some important aspects of VR. Is well known that VR simulators facilitate repeated practice of standardized tasks to help surgical trainees become familiar with specific psychomotor skills before performing procedures in the operating room, which is a stressful and high-cost environment. Moreover, simulators offer the possibility to quantify surgical performance on the basis of objective measures, which provides an unbiased assessment of surgical performance and individual progression[10]. Patient-specific training, based on pre-operative CT scan images, is a promising tool that has been tested on some simulating platforms. For example, Symbionix Angio-Mentor demonstrated increased procedural training without added risks to the patient. Moreover, it has been included in the Fundamentals of Endovascular Surgery skills testing, which is now required for certification in general surgery in the United States.

In a review article from the Cochrane Collaboration published in 2013, Nagendran et al[11] evaluated the role of virtual reality for surgical trainees in laparoscopic surgery. They report that virtual reality training appears to decrease the operating time and improve the operative performance of surgical trainees with limited laparoscopic experience when compared with no training or with box-trainer training. We may hypothesize that improved operative performances correlate with better outcomes for the patient. Clearly, it may lead to a more cost-effective learning curve, with a decrease of procedure/error related costs. Unfortunately, there are no evidences to support such a statement[11].

While data in the literature are inconclusive about the efficacy of VR-based preoperative planning, data reported in this review clearly show that preoperative simulation improves surgical performances in subjects naïve to minimally invasive procedures. On the other hand, AR seems to be confined to highly specialized centers up to now. One of the major limitations of this tool is its incapacity to adapt to organ deformation during surgery. AR-data are elaborated starting from pre-operative, static, CT-scan images: currently, real-time "adaption" to breathing and manipulation of anatomic structures during surgery is the main research topic. New tools like the head-mounted displays have been tested for application of AR[12,13]. In particular, Dickey et al[13] reported the outcomes of the use of Google Glass as AR interface in the operative setting of inflatable penile prosthesis (IPP) placement, using voice-command or tapping gestures to navigate. Authors reported that after stratifying results between trainees and faculty, educational usefulness was found to be 8.7 *vs.* 8.4, respectively, on a 10-point rating scale. Ease of navigation was found to be 7.5 *vs.* 7.9, respectively. Likelihood to use was found to be 7.4 *vs.* 7.5, respectively. Distraction in the OR was found to be 4.7 *vs.* 5.4, respectively. Also, specific comments given by participants recommended the inclusion of voice activation, patient and staff educational components for the procedure, video recording in the OR instead of streaming only, the ability to pull up patient imaging from while operating, and magnification. A recent paper on VR by Willis et al[14] is correctly titled: "Virtual Reality Simulators: Valuable Surgical Skills Trainers or Video Games?". In other words, is VR just "nice" or actually represents a useful tool for training? It seems that the major obstacle to the diffusion of VR-based training and VR-technologies in general surgery is a cultural limitation of surgeons themselves. As reported by Pessaux et al[8], the ability to guide surgeons during complex procedures is an opportunity to increase safety and overcome minimally invasive surgery limitations. Patient-specific anatomy is currently evaluated in the pre-operative setting through classical radiological imaging, that besides their advancements[15] still have a great intrinsic limit: they describe 3D anatomical spaces by series of 2-dimensional (2D) images. Therefore, the analysis and understanding of the whole amount of pictures to create a precise mental model of the target anatomy remains limited to radiologists and few surgeons who have a specific radiological knowledge and a large experience. Conversely, the medicine of the future is frequently defined as "patient-tailored", and the creation of VR-based models from patient's CT or MR images can fulfill this concept. Such models would be useful instruments to get trained safely on patients' anatomical singularity, and to improve outcomes in the real-life setting.

Besides surgery, other medical specialties may take advantage from VR. For example, recent studies demonstrated the benefits of VR in the management of neuropsychiatric disorders. Virtual environments were used to assess craving and reinforce cue-exposure therapy by displaying alcohol and drugs to patients suffering from substance use disorders[16]. VR also proved to be a valuable assistive, educational and therapeutic tool for patients with high-functioning autism[17].

CONCLUSIONS

Developing and validating an appropriate training system outside the OR with the application of all the technologies reported in this review represents the current challenge for every medical and surgical school. These novel technologies are not just toys for "grown-boys" and are likely to improve clinical outcome if applied appropriately.

Conflict of Interests:
The Authors declare that they have no conflict of interests.

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